NASA SP-51

N64-30326 N64-30350
(ACCESSION NUMBER) (THRU)
205 1
(PAGES) (CODE)
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(NASA CR OR TMX OR AD NUMBER) (CATEGORY)
FACILITY FORM 602

Fourth National Conference on the

PEACEFUL USES OF SPACE

BOSTON, MASSACHUSETTS

April 29–May 1, 1964

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION · U.S.A.

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Proceedings of the Fourth National Conference on the

PEACEFUL USES OF SPACE

Held in Boston, Massachusetts

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Scientific and Technical Information Division 1964
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Washington, D.C.

The conference was arranged by the New England community in cooperation with the National Aeronautics and Space Administration.

General Conference Chairman: JOSEPH A. ERICKSON
Chairman
New England Council

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D. C. 20402 Price $1.50

FOREWORD

This conference offers a valuable opportunity to study in depth the present and potential uses of our rapidly developing space technology.

As President Kennedy wrote just before his death, our national space effort "is expensive, but it pays its own way for freedom and for America. For there is no longer any fear in the free world that a Communist lead in space will become a permanent assertion of supremacy and the basis of military superiority. There is no longer any doubt about the strength and skill of American science, American industry, American education, and the American free enterprise system."

With fears and doubts dispelled, we can look forward to greater gains in space. We can seek new knowledge of the universe and man's place in it. We can send explorers to the Moon and planets. We can undertake great adventures which inspire our youth and in which all the world may share. We can develop practical uses of space and space technology which will profoundly affect our lives during the remainder of this decade.

The space competence we are acquiring is a great new national resource—if we use it as such. Our generation has learned to build the first crude tools of the new Space Age. As we labor to improve them, let us also learn to use them well for the benefit of mankind. That, in short, is the purpose of this conference, and of many more to come.

JAMES E. WEBB
Administrator
National Aeronautics
and Space Administration

CONTENTS

SPACE AND THE NATION

Chairman
JOSEPH A. ERICKSON
Chairman
New England Council

INTRODUCTION TO

SPACE AND THE NATION

JOSEPH A. ERICKSON
Chairman
New England Council

The U.S. Space Program is a complex and demanding venture. As our President said in his State-of-the-Union Message, "We must assure our preeminence in the peaceful exploration of outer space." As a New Englander, I also like to think of a statement of our late President Kennedy, "Peace is the new ocean, and we must sail on it." This seafaring metaphor is certainly appropriate to New England where years ago our clipperships created new social and economic impacts. Today, our spacecraft sailing into space hold an equal promise of discovery.

The purpose of this conference is to identify the challenge, the responsibilities, and the opportunities of the space program and to show all of us the ways and means of contributing to our national goal to our own advantage and to the advantage of our Nation. We have, therefore, arranged a program covering all aspects of space. We have brought together those who have managed the space program, as well as the leaders of local universities and industry.

This conference, the Saturday program for students, and the extensive and fascinating display of space systems and machines in our space exposition at Northeastern University have been planned to interpret the Space Age to New England. These events are cosponsored by the New England community and NASA and are financed by New England organizations. We hope to develop a better understanding of the space program and its potential. We also hope that you will see the challenge, accept the responsibility, and grasp the opportunity.

WELCOME

Endicott Peabody
Governor
Commonwealth of Massachusetts

I welcome you as a New Englander—as a member of that six-State community which has had an influence on the country, and indeed the world, far out of proportion to its size. Leaf through the pages of old, recent, and contemporary history, and you will find individual New Englanders who, by their force of character and depth of thought, have profoundly influenced their times. You all know the proud roll call of these names—from Adams to Kennedy, from Lowell to Whitney.

One not so well known, who is perhaps the real reason why we are here today, is Robert H. Goddard, a native of Worcester and once a professor at Clark University in Worcester. It was in 1919 that he sent the 69 pages of some years of research to the Smithsonian Institution. His manuscript dealt with "A Method of Reaching Extreme Altitudes." He made mention of shooting a rocket to the Moon. On March 16, 1926, he launched the world's first liquid-fuel rocket from a field in Auburn, Mass. Three years later, in July of 1929, he launched the first instrumented rocket. Its instruments consisted of a barometer and a thermometer, and a camera for recording their readings at maximum altitude. His pioneering is today memorialized in NASA's Goddard Space Flight Center in Greenbelt, Md.

We treasure the past in New England, but we cannot—and do not—live by the past alone. When today's sounding rockets probe the outer atmosphere of man's environment; when satellites circle the Earth providing service to mankind in the form of new means of communication, navigation, or weather control; when astronauts orbit the Earth in manned space flight—then, all these prodigious efforts share a common denominator. With them ride the theories and products of New England's universities and industries. They will ride, too, with the men who land on the Moon—surely the most challenging, the most complex, and the most dramatic journey ever made by man.

New England is therefore contributing to our Nation's space program. But . . . can we do more? Is our potential fully known and fully recognized? These questions are central to the economic development of our six-State region. They are central to our country's leadership in space—a new national imperative.

NASA itself has asked these questions, and NASA has answered them in several ways. Almost 2 years ago, NASA sent from Washington a trusted aide of the administrator, Franklyn W. Phillips, to open NASA's first regional office here in New England to foster the interchange between the U.S. space program and the region. Within the past few weeks, the Congress and NASA have decided to place the new electronics research center in New England, and thus challenge our capabilities and provide us with an added opportunity and incentive to utilize our own resources.

Today, with NASA's encouragement, the New England community is playing host to the Fourth National Conference on the Peaceful Uses of Space. This in itself is an unrivaled opportunity for the community as a whole to come into contact with the challenge of the U.S. space program.

I would like to compliment and congratulate the New England community for creating and supporting such a venture—notably the advisory committees drawn from each of the six States, and the dedicated efforts of the general chairman, Joseph A. Erickson, who undertook the job at my invitation, and his supporting committees. The community's thanks, and mine, should also go to James M. Gavin of Arthur D. Little, and James Killian of MIT, who personally and or-

ganizationally have contributed much to the conference. The university complex has played an important role in this conference, and particular mention should be made of Dr. Asa Knowles of Northeastern University, who has given over the university field house to the brilliant exposition of space machines and space sciences which accompanies this conference, though I understand Northeastern's baseball and track coaches do not altogether share my enthusiasm.

A glance at the program reveals how solidly NASA is supporting the conference. Participants include the heads of NASA programs, the directors of NASA Centers, and the administrators of what in justice has been called man's greatest peacetime venture. I think we are all particularly complimented by the keynote speaker, Dr. Hugh Dryden, the Deputy Administrator of NASA, an internationally known scientist and public servant. His presence honors us all and sets a standard of excellence for the whole conference. May we all profit—businessman, educator, scientist, layman, and student alike—from the lessons of the conference to the advantage of our New England region, and our Nation. This is a challenge to us. May we meet it.

N64-30327

TO SAIL THE NEW OCEAN OF SPACE

HUGH L. DRYDEN
Deputy Administrator
National Aeronautics and Space Administration

The most advanced technological development of our time came to the notice of the world on October 4, 1957, when man sent into space the first artificial satellite of the Earth, the Soviet Sputnik. That first venture into space could have been ours—we had the ability to do it but not the foresight or the determination. This event was followed by the establishment in our country of the National Aeronautics and Space Administration, which came into existence officially on October 1, 1958. These events and the events of the intervening 6 years have had a profound impact on human affairs throughout the world, and especially within our own country. Repercussions have been felt in science, industry, education, government, law, ethics, and religion. No area of human activity or thought has escaped. The toys of our children, the ambitions of our young men and women, the fortunes of industrialists, the daily tasks of diplomats, the careers of military officers, the pronouncements of high church officials—all have reflected the all-pervading influence of the beginning steps in space exploration.

The exploration of space is a continuation of the geographical exploration by man of unknown areas of the earth from the days of the Phoenician mariners 3,000 years ago. The New World, the polar regions, the depths of the ocean, the limits of the atmosphere—have each in turn been the temporary goal. Space is the new frontier.

Ralph J. Cordiner gave an interesting analysis of this new frontier in his lecture in the "Peacetime Uses of Space" series of the University of California:

> At this stage, the new frontier does not look very promising to the profit-minded business man, or to the tax-minded citizen. . . .
>
> Every new frontier presents the same problem of vision and risk. . . . Leif Ericson discovered America 500 years before Columbus, but apparently the Vikings did not have the vision to see anything worthwhile on that vast, empty continent, and so history waited for another half millenium. . . .
>
> When a new frontier is opened, the new territory always looks vast, empty, hostile, and unrewarding. It is always dangerous to go there, and almost impossible to live there in loneliness and peril. The technological capacities of the time are always taxed to the utmost in dealing with the new environment. . . .
>
> It takes an immense effort of imagination for the citizens to see beyond these initial difficulties of opening a new frontier. No one would pretend to foresee all the economic, political, social, and cultural changes that will follow in the wake of the first exploratory shots in space, any more than the people in the days of Columbus could foresee the Twentieth Century world. But such an effort at prophetic imagination is what is required of us as citizens, so that we will not, like Leif Ericson, leave the making of the future to others.

We have as a nation accepted the challenge of the new frontier and this year are spending a little more than $5 billion on the exploration of space for peaceful purposes. This represents an expenditure of approximately 50 cents per week by each of the 200 million inhabitants of our country. We have mustered a great array of manpower, money, and scientific and engineering talent for a peaceful undertaking—on a scale formerly reserved only for making war. I find great hope for the future course of mankind in the fact that we can mount such a vast scientific and engineering effort in the name of peace.

At the end of 6 years of intensive effort on the part of many thousands of dedicated citizens in industry, government, and the universities of the Nation, we are moving from a period of preparation to one of fruition.

Six years ago, before the Nation began to take space exploration seriously, and before NASA was formed, the United States managed, with great effort, to put a very small spacecraft of 31 pounds and limited capability in orbit. Plans were made immediately to over-

come the great disparity in capability between ourselves and the Soviets by initiating the Saturn I launch vehicle of 1½ million pounds thrust, utilizing existing small engines in a cluster of eight, by initiating the developing of the large F–1 engine with 1½ million pounds thrust in a single combustion chamber and nozzle and by initiating the application of liquid hydrogen-liquid oxygen fuels in the RL–10 engine. We began to explore space insofar as we could with the limited tools available.

On January 29th of this year, the plans for the Saturn I came to fruition, with its liquid hydrogen-liquid oxygen second stage, as the most powerful rocket known to exist placed the heaviest load yet in orbit—38,700 pounds—corresponding to a payload weight of more than 10 tons. We have developed many of the necessary tools and now have the capability of doing many more missions than available resources will permit. We are not only moving into a period of fruition but one in which we must look to refinement of the technology already developed and the scientific knowledge already gained. Most important, it is imperative that we look ahead to the things we must do now, or soon, to prepare for the space missions which the future will demand of us if we are to maintain leadership in space.

The history of research and development in advanced areas in this country is one of repeated preoccupation with the current requirements of the Nation at the expense of, or to the neglect of, the basic long-range efforts needed to maintain leadership in vital areas of science and technology.

Because of the initiative and the daring of the Wright brothers, this Nation gave man the capacity for powered flight, freeing him forever from the bonds which for thousands of years of human existence had confined his activities to land and sea. The United States became the first country in the world to possess a military airplane when, in 1908, the Army Signal Corps contracted for a Wright biplane.

Yet prior to World War I this Nation was still so preoccupied with conventional weapon systems that it totally neglected the development of aeronautics—the force which was to dominate warfare for the next quarter century. In 1914 the United States possessed fewer military aircraft—and of inferior types—than the six leading aeronautical nations (including Mexico). The United States in 1914 was the only major nation in the world not to possess an aeronautical laboratory with an up-to-date wind tunnel. By November 1918 not one aircraft of American design and manufacture had entered combat operations during World War I.

In the thirties we were so preoccupied with refinement of conventional piston-driven aeronautical systems that we made little progress in jet propulsion. Meanwhile the Germans set out to build a bigger and better NACA, predecessor agency to NASA; and to a large extent they did, developing jet-propelled military aircraft and 5½–ton V–2 rockets which almost spelled disaster in World War II.

In the late forties, despite the fact that Robert Goddard had demonstrated the feasibility of a liquid-fueled rocket engine in this country in 1926, and despite the memory of the V–2's raining on London during the blitz, we were so preoccupied with mating jet carriers to our exclusively held atomic-bomb capability that we neglected missilry while other nations forged ahead. And finally, in the fifties, our A-bomb advantage gone, we were so preoccupied with the development of our ballistic missile program that we neglected a clear opportunity to become first in space.

Today the Nation faces—we all face—this question: Have we learned enough from the often bitter and always costly experience of the last half century not only to carry out with determination this effort to meet the requirements of the present in space research and exploration but to exercise the vision which is demanded if we are not, once again, to find ourselves lagging in the next phase of this most challenging effort?

It must be hoped that we have learned enough from the sequence of events which I have just described to put aside for all time any feelings of comfortable assurance that science and technology are areas in which the United States will remain firmly and forever supreme. It is not surprising that we should have felt such assurance in the past, for we did, as a nation, establish an early technological ascendancy over the other countries of the world. But it is equally clear that many other nations have overcome our early lead and that future leadership in this competition, which has such great economic, military, and political significance, will not be easily held or won.

Thus, while we may all glow with pride over the Nation's recent accomplishments in space and our part in making them possible, we must not delude ourselves or the Nation with any thought that leadership in this fast-moving age can be maintained with anything less than determined, wholehearted, sustained effort.

The present gap in manned flight activity is a direct consequence of a postponement of the decision to proceed beyond Project Mercury from September 1960 until May 1961, when the late President Kennedy recommended the present manned lunar landing project as a national goal.

The decisions which confront us today are those which will determine whether this kind of history will repeat itself a few years hence and whether we will once again experience a bitter awakening to the fact that others have seized the initiative in the more advanced space missions of the future.

If one looks at the history of NACA, it is apparent that the aeronautical research conducted by that agency not only brought this country to a position of leadership in civil aviation but in military airpower as well. I well recall the statement of Frank Knox, the Secretary of the Navy in 1943, which pointed up the NACA contribution to airpower, and which, I am convinced, will apply with equal force to the NASA contribution to defensive strength in space. He said at that time:

> New ideas are weapons of immense significance. The United States Navy was the first to develop aircraft capable of vertical dive bombing; this was made possible by the prosecution of a program of scientific research by the NACA. The Navy's famous fighters—the Corsair, Wildcat, and Hellcat—are possible only because they were based on fundamentals developed by the NACA. All of them use NACA wing sections, NACA cooling methods, NACA high-lift devices. The great sea victories that have broken Japan's expanding grip in the Pacific would not have been possible without the contributions of the NACA.

Within recent weeks we have seen the first major example of the application of NASA research to military use, with the decision to employ Gemini technology in the Air Force MOL (manned orbiting laboratory) project. But this is merely the forerunner of similar applications not only in manned operations but in navigation, communications, and meteorology as well.

Our present major goals in space exploration were set by the late President Kennedy on May 25, 1961, following study and recommendation by President Johnson, then the Vice President and the Chairman of the National Aeronautics and Space Council. A definite decision was made to achieve a position of leadership in space science, space technology, and space exploration. One specific goal was to develop the capability for manned operations in space out to the distance of the Moon and to demonstrate this capability by sending a team of American explorers to the Moon and back before the end of this decade.

President Kennedy said to the Congress and to the Nation:

> I believe that this nation should commit itself to achieving the goal, before this decade is out, of landing a man on the moon and returning him safely to the earth. No single space project in this period will be more impressive to mankind, or more important for the long range exploration of space; and none will be so difficult or expensive to accomplish. . . . But in a very real sense, it will not be one man going to the moon. . . . if we make this judgment affirmatively, it will be an entire nation. For all of us must work to put him there.

Under the leadership of President Johnson, who has long advocated a strong national space program and who was one of the principal architects of the National Aeronautics and Space Act of 1958, we are making progress toward fulfillment of our destiny of becoming the world's leading spacefaring nation. We are proceeding to master this new environment as we have mastered the land on which we make our homes, the ocean which carries our ships, and the air that sustains us.

President Johnson reaffirmed the lunar exploration goal in his 1963 Budget Message in these words:

> Our plan to place a man on the moon in this decade remains unchanged. It is an ambitious and important goal.

We have chosen to go to the Moon because manned exploration of the Moon involves every facet of overall space capability this Nation must develop if we are to become a leading spacefaring nation. Also, the Moon's pockmarked surface, untouched by water or wind erosion since it has no atmosphere, bears the traces of everything which ever occurred there. But some say: "What do we want of the vast worthless area? To what use could we ever hope to put these deserts or these endless mountain ranges?" These identical words were used by an illustrious Senator from Massachusets in 1844. Daniel Webster was opposing an appropriation of $50,000 to extend mail service to California.

We do not know whether we will find materials of economic value on the Moon. Lawrence Lessing, in a recent article in *Fortune* magazine, made the point that the most compelling reason for space exploration is the accumulation of knowledge. He says, in part:

> The purposes of this (space) exploration are no clearer to many men in this age than they were in

Galileo's, so it is not strange that there is opposition. In this economic age, however, the opposition is not so much theological as budgetary. Both seem equally mistaken in the context of their times. . . . new knowledge is a dukedom whose great wealth and resources cannot even begin to be estimated or exhausted. Already the new knowledge acquired in space exceeds by far the value of funds so far spent. For knowledge, more than guns or butter, is the true power of modern states.

The plan for reaching the Moon in Project Apollo, as the culmination of our efforts during this decade to master the new environment of space, calls for sending three astronauts into orbit about the Earth and then on a course toward the Moon. Near the Moon a rocket is fired to slow the Apollo spacecraft so that it goes into an orbit around the Moon. Two astronauts then transfer to a Moon ferry vehicle, fire a retrorocket, and descend to the lunar landing, using rocket thrust as a braking force since there is no atmosphere. The crewmen take turns leaving the ferry vehicle in their lunar space suits to explore the cratered surface of the Moon.

Returning to the ferry vehicle, the two astronauts fire rockets that shoot them upward to rejoin the Apollo spacecraft and then head back toward Earth and the tiny corridor about 40 miles high through which they can safely enter the atmosphere from space. Protected by a heat shield and in the later stages slowed by atmospheric drag and by parachutes, the astronauts return to Earth.

To perform this mission many capabilities must be developed and practiced, including the develpoment of rockets capable of launching the required load to the Moon, of making path corrections, of braking, and of taking off from the Moon; the development of the technique of bringing two spacecraft together in space, which we call *rendezvous*; the development of the technique of physically joining them to become a single spacecraft, which we call *docking*; the development of capability of astronauts to operate outside the spacecraft in space; the development of maneuverable spacecraft; and the development of guidance and control for all phases of the mission including reentry.

The development of rendezvous and docking begins with Project Gemini, which also permits an early test of the capabilities of men and machines up to periods of 2 weeks. Gemini involves a two-man spacecraft, a logical second-generation spacecraft emerging from the successful Mercury program. On April 8 the first unmanned orbital flight test of Gemini was successfully accomplished, and it is expected that the first manned flight will occur about the end of this calendar year.

The Apollo three-man spacecraft will be fully exercised in Earth orbit, practicing near the Earth the rendezvous and docking maneuvers with the actual vehicles later to be used near the Moon. It is estimated that NASA astronauts will have accumulated at least 2,000 hours of space flight time before we attempt the Moon voyage.

The achievement of our space goals requires hard work, resourcefulness, and daring. It requires the skills and abilities of scientists, engineers, educators, industrialists, artisans, and craftsmen all over the Nation; and it requires the determination of the American people. It is the aim of NASA to marshal a nationwide team of the most competent participants working toward a common goal in such a manner as to strengthen our free institutions in industry, universities, government, and local communities.

We are carrying forward an active national space program—not limited to the Moon—encompassing science, advanced engineering, practical applications, including manned space flight.

We are building toward preeminence in every phase of space activity—all the way from microscopic electronic components to skyscraper-tall rockets.

We are building a network of large-scale engineering facilities, space yards, proving grounds, and space ports to assemble, test, and launch the space vehicles we need now and in the future.

We are creating new national resources of lasting value in these facilities, in the industrial and managerial capabilities we are developing, and in the growing number of scientists and engineers who are learning about space and space technology.

We are filling the pipelines of hardware and knowledge and, as measured by the financial resources required, will be halfway toward our first manned lunar mission by mid-1965.

We are accumulating, in space, the basic scientific knowledge about the Earth, the solar system, universe, and about man himself.

We are bringing benefits not only to the United States but to all the world through the use of space and space technology, employing such new tools as weather, communications, and navigational satellites, and applying space-based techniques, equipment, and materials to improve industrial products, processes, and services.

We are providing a much-needed stimulus to the energies and creativity of people everywhere, particularly to the minds and aspirations of young people.

We are bringing about increased economic activity at a time when the effects of automation on our society are beginning to be felt.

And we are making certain, through our sustained efforts, that the realm of space now opening up to us shall be a domain of freedom.

It is for these reasons that we have mounted the greatest peacetime undertaking in the history of mankind.

I have emphasized the national character and scope of the program, but I am sure that the Northeastern area is finding and will find its role in the national effort. Other speakers from this region will no doubt give appropriate emphasis to the actual and potential participation of the universities and industrial firms of the community in the national program.

Congress gave its approval in March to NASA's plans to establish its Electronic Research Center in Greater Boston. The status of our plans is undoubtedly of interest to everyone in the Nation, since the Center will catalyze a much larger effort in research on problems arising from the use of electronics in space applications than is now in being, in part within the Center itself, but—as is characteristic of the general NASA program—also at the educational and industrial institutions of highest competence throughout the Nation. Our general plans have been described in detail in our report to the Congress on the Center.

Two top priority matters are now in progress, that of deciding on the specific location for the Center within the Greater Boston area and that of selecting the director. Both are being pursued urgently at this time but without specific schedules having been set for their completion. Too much of importance hinges on these decisions to be arbitrary in deciding when they must be made.

A Site Evaluation Committee, composed of six NASA officials from our headquarters and field staffs, is at work reviewing the many proposals that have been presented to us. Both urban and suburban sites are under consideration; and, whatever the final choice, NASA will want to insure a viable relationship between the Center and the university community in the area.

The selection of a director for the Center is not unlike the selection of a site, in that there are many candidates to be considered. NASA management is considering this matter carefully and will make its selection at the earliest possible time.

As we have advised the Congress, the buildup of the Research Center will take place at the most rapid rate possible that is consistent with the development of a competent, well-organized staff. It is estimated that it will take 4 to 5 years to reach our present goal of 2,100 people. We expect to house the first of these people in rented quarters that we will acquire later this year.

NASA wishes to get on with its plans for the Center. But the decisions immediately ahead of us are crucial to the successful integration of the Center into the Nation's space exploration team, and so these decisions must be made with care.

Almost a year ago today, at the Conference on Space Age Planning held in Chicago as part of the Third National Conference on the Peaceful Uses of Space, a message of greeting was sent by the late President John F. Kennedy. It said, in part:

> We know we cannot hold back tomorrow. The tomorrow of the space age is inevitable. For our Nation there can only be a determination that it will be a free tomorrow. We are outward bound. I am convinced that our broad and accelerating exploration of space will help bring this Nation to a destiny more splendid than any dreamed of by our predecessors.

This Fourth National Conference on the Peaceful Uses of Space may serve as the anvil on which we can forge our resolution that the limitless realm of space shall remain free.

As Deputy Administrator of the National Aeronautics and Space Administration, I am pleased to welcome you to this important conference. May your efforts meet with unqualified success.

N64-30328

THE SPACE PROGRAM AND NEW ENGLAND INDUSTRY

JAMES M. GAVIN
Chairman of the Board
Arthur D. Little, Inc.

Travel to the Moon is itself unimportant; it is merely a milestone in man's exploration of space. Landing on the Moon and establishing a research base and small colony there will merely be evidence that man has acquired sufficient knowledge to do so, and, more important, has applied it to his needs with effectiveness. But, more important—and more germane to this conference—is what he does with his newly acquired knowledge on Earth. Certainly in our time, not many of us will make the lunar journey or beyond; but the effort that our Nation makes to get someone there will—or can—have great importance to New England—if we are prepared to take advantage of the opportunity.

There is no magic formula to meet these opportunities; they will not drop into our laps; we have to work to find them and to take advantage of them.

We have been reading and hearing more and more of late about how defense spending is tapering off. Economists have been putting in long hours studying what the effects of this will be, and how we can keep them from being more serious than they at first appeared to be. While executives of defense industries are well aware of the need to convert to producing for the civilian economy, they are finding that it is not an easy job. The defense market has different requirements and requires a different kind of selling, and the science and engineering for the defense market respond to different motivations and require different practices.

It is possible that the space program may provide an alternative to the defense market. Certainly its growth in terms of dollars seems to indicate that the space effort promises to fill in behind the decline of the defense effort. For the fiscal years 1955 to 1962, appropriations for all space programs totaled $7.5 billion, while the present budget request for NASA is for $5.3 billion; and some have predicted that the 1970 NASA budget might amount to $9.5 to $10 billion.

Because reaching the Moon and beyond does not carry with it quite the urgency that characterizes national defense, these predictions may prove illusory. Many of the skills, practices, and requirements of this market are like those of the defense industry. It can be expected, then, that those companies skilled in the defense industry will receive many of the benefits of this younger effort. By the same token, the skills appropriate to the space program are not easily convertible to the civilian economy.

But other than as a substitute for a waning market, what is the significance of the space program to the New England economy? There are three very clear advantages.

The first benefit is counted directly in terms of dollars and cents. In fiscal year 1963, NASA awarded $53 million of prime contracts to New England firms—a fivefold increase in 2 years. And subcontracts coming to the region in the calendar years of 1962 and 1963 added another $70 million. Another $35 million in prime contracts were awarded during the first half of the current fiscal year. The subcontracts for that period, in addition, brought the space program up to a $50-million industry for New England companies for that 6-month period. Recently we learned that construction on the new electronic research center depends only on site selection and the appropriation of funds. This will mean over 2,000 new jobs during the next 5 years, with some $35 million in annual salaries, and operating costs, of which $18 million will be for purchase of goods and services.

When the Manned Spacecraft Center went to Houston, that city experienced a significant surge in its economy—$147 million in construction and equipment,

over 3,000 NASA employees receiving about $3 million in monthly salaries, some 85 aerospace firms sending another 2,500 representatives, and new jobs appearing to serve these new citizens have amounted to the addition of a sizeable new community in 2 years. During these same 2 years, almost the same figures were being chalked up because NASA established facilities related to the Saturn program. These are exciting figures to conjure with; but remember that New England already has the scientific and engineering talent, the experienced companies and the academic resources that made it the preferred location for the electronic research center. We cannot count on a comparable phenomenal growth.

But we can use our reservoir of talent and experience to attract an increased share of the space contracts, and so far we have obtained only 2 or 3 percent of the total each year.

The second benefit is that of the generation of new knowledge and technology in the course of solving the problems encountered in the space program. The military services have provided a wide variety of products for our society over the years, from clothing to food processing, as well as techniques such as operations research and systems management. It is not surprising that we should expect similar byproducts from the space program. The great disparity between the requirements of travel in outer space and our daily lives, however, means that these byproducts are not always as readily available. Several studies have been made to identify them, and the research organizations from my own company here in the Boston area to Stanford Research Institute on the west coast are engaged in a continuing effort to make them available to industry.

In this connection, James Webb has announced:

> It is our objective, in accordance with the directives given by Congress and the President in creating NASA, to insure that developments resulting from NASA's scientific and technological programs be retrieved and made available to the maximum extent for the nation's industrial and consumer benefit in the shortest possible time. . . .

Now, in order to accomplish this directive, NASA has created a Technology Utilization Division to locate, record, analyze, and disseminate the developments resulting from the program. Officers are continually working to uncover such developments and to make them available.

By waiver of the Government's rights, contractors may be permitted to own and to patent inventions made in the course of their work if they will agree to take steps toward commercial development within a reasonable time. And NASA readily grants licenses on its patents provided the licensee will endeavor to put them to use within 2 years. Every effort is being made to get these new developments out to those who can make good use of them. As part of this effort, news of new techniques is published in "Application Notes" and "NASA Tech Briefs" that are prepared by NASA's Technology Utilization Division.

About 5 or 6 years ago, as I considered the significance of the space program, it seemed to me that the fallout benefits to our consumer product economy might be very worthwhile. At the time we were concerned with the heat barrier, and as we sought to solve that problem, we tried to think of commercial uses for the highly resistant materials we were experimenting with. We also, of course, were dealing with materials for the engineers as well as many of the other missile components. We were looking, too, for lightweight, high-yield energy sources, and as we sought solutions to our many pressing problems, we explored the extremes of the temperature spectrum for new processes and new materials. From all of this, much has been devised that will be useful in our civilian economy, but so far one of the most interesting aspects of this experience has been the amount of information uncovered that has immediate application to the human being, himself—to biology, to bioengineering and to biochemistry. Many of the sensory devices, data processing, and presentation systems have proven useful in diagnostic and surgical practices as well as other treatments of biological problems. This, to many, has been somewhat of a surprise and rather serendipitous. But it is an indication of the value of the unexpected in this type of basic and applied research in new areas.

The *New Yorker* has just finished a series of articles on the scientific and technological community here in Greater Boston. The editors entitled the series, "Center of A New World." It was Oliver Wendell Holmes who called Boston the "Hub of the Solar System"; now Christopher Rand has refurbished the old title. He wrote these three articles about the astonishing pool of talent; this pool of talent is the third benefit the space program can bring to New England. It is true that Harvard, Yale, MIT, and the other schools and colleges of the region antedate the space effort; indeed, Dr. Goddard did most of his pioneering work with rockets right here at Worcester. (We might al-

most claim that this area is the cradle of the space effort.)

The work of NASA should add significantly to this resource. The growth of "science-based" organizations around here has been described as being analogous to the phenomenon of a "critical mass." After a certain point, the reaction carries on by itself—like begets like. With the start in World War II of scientific projects like the forerunner of Lincoln Laboratories, such organizations have grown at an increasing pace here, attracting others along with the service companies that supply them. Clearly this pool of talent was a determining factor in the contested decision to establish the NASA Electronic Research Center here and to keep the Air Force research activities at Hanscom Field.

But by the same token, these activities attract still more such talent here. Similar growth is beginning in the Houston area and is well established on the west coast. So we can expect to benefit from the addition to our talent pool as a result of the space effort.

We are fortunate in that this talent clearly has applications to our life on this Earth as well as to our efforts to reach into outer space. My predecessor as president and chairman of Arthur D. Little, Inc., Earl Stevenson, has been carrying on some very interesting research into the convertibility of new knowledge and talent from research activities for governmental programs to the needs of the civilian economy. He believes that in many ways they are two different worlds. There is much justification for this conclusion of his, and something similar may be true in the industrial scene, where defense-oriented companies are finding it difficult to move into the civilian economy.

This can be a real long-run danger. However much we may welcome the growth of first defense, and now space projects, if we cannot keep such work balanced by civilian production, we shall find our regional economy dangerously lopsided and a victim of future changes in national policy. That is why we are fortunate in having "transferable" talents here. As one example, the second *New Yorker* article discussed the computer "industry" as it is seen at Harvard and MIT. Much of our special talent lies in electronics, an essential element in computer technology. This is but one way in which electrical engineers will be able to contribute civilian needs. The universities may provide the means by which much of this talent can be used, since their work is as pioneering as that of the space effort.

In a recent list of 35 major defense-space contractors, only 2 large New England firms were heavily involved in comparison to their total sales. We should try to keep a good balance between civilian economy and space economy so that our civilian regional economy also contributes to and benefits from the space program. I noticed with pleasure a newspaper story about the David Clark Co., of Worcester, which makes knitted garments but is also working currently on a contract for NASA on the space suit to be used in Project Gemini. For quite a while now, some of the products of a small, Boston electronics company have been the computers in satellite guidance systems orbiting in space, but these devices and the technology that produced them also find many uses in civilian products and processes. Here, it seems, is the basis for a viable growing economy for our region.

We need the long-term strength of selling to the everyday market here on Earth; but we also need the stimulus in dollars and challenge and new knowledge that contributing to the space program can bring. For it is a challenge, this dealing with problems posed by conditions we have never met before. And it is a challenge to learn to use these new developments and ideas to their fullest advantage. Most people attend carefully only to experiences which are immediately significant in their own everyday life. They perceive in terms of their preexisting values and attitudes; they try to mold new experiences into old contexts; and thus the new experiences frequently lose their unique implications and power. If the experiences do not fit this standard context, they are likely to be ignored altogether. It is to avoid this happening that our businessmen must be responsive to the challenge and sensitive to the nature of the rapidly changing technological environment in which we work.

As a corollary, that is why we welcome the challenge that the national effort to reach the Moon can supply. New conditions bring new problems, some of which can be solved only by seeing them in a new way. We shall benefit from the talents brought by NASA to our region just as surely from the contagion of their new perspectives as we shall from the new dollars they bring to our stores and the new products they can make possible for us. Max Lerner, in writing about the social implications of the space effort last year, concluded with this thought:

> The knowledge generations in our time succeed each other every decade, each decade bringing with it some-

thing like a doubling of what is known and must be mastered. But the emphasis will have to be not on piling up new knowledge upon new knowledge, but on knowing the implications of what we know.

In the history of science the leap of intuition has always played a greater role than the stodgy men have been willing to admit. The orbiting mind is not the answer to the problem of a spacious society: to swing endlessly in the same groove is only another way of standing still. The task of our generation, even more than the breakthrough into outer space, is the psychological breakthrough into the inner man in order to escape the circle of rigidity that still holds him in thrall.

N64-30329

NEW ENGLAND: A RESEARCH-RELIANT REGION

J. R. Killian, Jr.
Chairman of the Corporation
Massachusetts Institute of Technology

New England is developing into a research-oriented, research-dependent region. More and more its stock in trade is innovation, its life and work shaped by creative activities not only in fields such as science and technology but in many others. By taking the lead in innovation, in the arts, in the sciences and engineering, in craftsmanship, in the social sciences, in scholarship, and in other ways, New England has the chance steadily to renew its economy and to provide opportunities for its people to find fulfillment, each creative after his own fashion.

The great adventure of space provides our region a tailormade opportunity to exploit its specialized resources for innovation. By way of example, let us consider the interrelations of our national space program with education in New England and then discuss ways to insure that we do indeed take full advantage of our opportunity to become a research-reliant region.

Lest there be any misunderstanding, I would first make clear my views about the central role of educational institutions. Their primary responsibilities are teaching—the nurturing of new talent—together with the quest for new knowledge, and the perpetuation and dissemination of this knowledge. These responsibilities require an environment benign to scholarship, to contemplation and creativity, to disinterested curiosity exercised in freedom, and to ideal aims and long-term goals. The more successful our universities are in pursuing these goals and in maintaining these characteristics—in performing their special, time-honored function—the more successful they will be in serving needs of the economy and the Government. In discussing their relation, therefore, to the space program or any other program of national service, I emphasize that our educational institutions must first and foremost be places "of light, of liberty, and of learning," where there is a lively interaction of questing young minds, fresh and eager in outlook, with older minds full of wisdom and learning.

Since space exploration involves so many frontier problems and skills, it is not surprising it touches practically every discipline represented on the university campus—especially in science and engineering, but also in management, the social and behavioral sciences, and the humanities. We see this reflected in the kinds of space-related programs that are now to be found in our New England institutions. As Dr. Hugh Dryden has said, space is a social force which the university cannot ignore.

NASA's national program in colleges and universities sets the pattern for New England. In the short span of 6 years, NASA has grown to where it now accounts for about one-third of the Federal Government's total annual expenditures for research and development and almost half the Federal funds allotted for basic research. NASA expenditures at universities are now on the order of $90 million per year, with about half of this obligated under its sustaining university program and the other half in specific project grants for basic and applied research and development. University scientists and engineers have been involved in the space program since its inception, proposing and preparing equipment for most of the experiments carried in our scientific satellites and space probes or undertaking supporting research in the laboratory on such matters as energy conversion, heat-resistant and radiation-resistant materials, and inertial guidance systems. These experiments and research projects are carried out under specific project grants assigned to individual investigators, who usually in turn involve other professional colleagues and their students in the research. At the present time, it is estimated that over 4,000 experimenters located on

some 130 university campuses are participating in NASA-sponsored research.

NASA's sustaining university program was begun in 1962, and essentially it is aimed at some rather important long-range goals. Foremost among these is recognition of the need to replenish and augment the nation's supply of highly trained scientific and technical manpower by encouraging able students to complete their work for the Ph. D. degree. Specifically, this training-grant program, as it is called, makes available to the individual graduate student an annual stipend of between $2,400 and $3,400 for a period of 3 years, in the hope that this will enable him to spend full time on his graduate study and complete his doctorate within a minimum time. The training grants are made by NASA to universities rather than to individual students and include an allowance with which the university can strengthen its graduate program in space-related sciences and engineering. The university also has full discretion in awarding individual predoctoral fellowships within its program, on the theory that the university itself is in the best position to evaluate a candidate's interests, qualifications, and need. At present there are 1,071 predoctoral candidates receiving support under this training-grant program at 131 universities, and eventually NASA hopes to add other universities having Ph. D. programs in the sciences and engineering and to have approximately 4,000 students in the "pipeline" to yield about 1,000 new Ph. D.'s each year in scientific and technical areas.

There are two other phases of NASA's sustaining university program. One is its grants-in-aid for construction of laboratory facilities at universities where needed for NASA-supported research. So far, there have been a total of 15 such facilities grants amounting to $17,642,000 to provide 504,000 square feet of new research laboratory space.

The other phase of NASA's sustaining university program is designed to stimulate wider university participation in long-range interdisciplinary research on the very forefront of all the sciences and engineering that may have a bearing on the future success of our space effort and space missions. This program is also designed to help build research strength in new fields in universities which have the latent capacity to grow into new centers of strength in research and graduate education. At present such special research grants have been made to 18 universities and involve a total of about $11 million.

Educational institutions in New England are well represented in both NASA's sustaining university program and its specific research project grants. At present 89 predoctoral candidates at 15 New England universities are receiving NASA training-grant support; this represents 8 percent of the total trainees and funds involved and 11 percent of the universities in the national training-grants program. Of the 18 universities that have received special interdisciplinary research grants, 2 are located in New England. These are MIT and the University of Maine.

Facilities grants-in-aid have been made to MIT for construction of its multidisciplinary Center for Space Research and to Harvard for a biomedical research annex to its cyclotron for studies of proton interactions with biological materials, from which we will be better able to predict the risks of solar flare radiation to our astronauts and establish shielding criteria for manned spacecraft. Harvard also has a privately funded space-related biomedical research laboratory. This is the Guggenheim Center for Aerospace Health and Safety, which has been functioning for 6 or 7 years as a part of Harvard's Graduate School of Public Health.

There have been over 75 specific research and development projects undertaken with NASA support at 17 New England educational institutions. Among these are development of equipment for an optical satellite-tracking network by the Smithsonian Astrophysical Observatory, which shares staff and quarters with Harvard's Observatory in Cambridge, and the development responsibility that MIT's Instrumentation Laboratory has for the Apollo guidance system. Members of the New England university community have also made the first observations of the solar wind and the first measures of the boundaries of the earth's magnetosphere. They are undertaking theoretical research in relativity, cosmology, cosmic rays, and the physics of stellar interiors and making magnetohydrodynamic studies to explain the structure of spiral galaxies. They are developing instruments suitable for measuring neutron intensity in space and studying the mechanisms of alloy strengthening. They are determining the effects of plant growth hormones on plant development in the absence of gravitation and devising methods for remote automatic detection of bacteria. They are helping to create a new branch of geology—planetary geology—and are contributing to a better understanding of the kind of electrified plasma through which our earth moves.

NASA is also sponsoring research into the organization and management of large-scale technology-based enterprises, this study being the responsibility of the Sloan School of Management at MIT. And a group of three teachers' colleges in Maine and the University of Bridgeport in Connecticut have NASA grants to develop teaching materials in astronomy and other space sciences appropriate for students in the elementary grades.

These activities in our universities reflect the interest on the part of faculties and students in space science and engineering, together with their recognition of the needs of our space programs and the ways in which colleges and universities can help meet these needs. Unquestionably the space program has captured the imagination of students, especially those in engineering.

The activity of MIT may be cited as an example. More than 100 members of our faculty are now engaged in space-related education and research. On last count we had more than 180 graduate students involved in space research, and in 1960–61, 15 percent of our candidates for advanced degrees presented theses in fields related to space.

It is clear that space technology, as viewed by scholars in our universities, affords new opportunities for scientific observation and experiment, and for great advances in technology, which will add to our understanding of our own earth, its solar system, and the universe. It is clear, too, that NASA is contributing greatly to the pursuit of this understanding in our New England colleges and universities, and that our educational institutions are important factors in giving New England a place in space.

We may note with satisfaction the scientists and engineers from New England educational institutions who are providing top-level advice and assistance to NASA. The Science and Technology Advisory Committee for Manned Space Flight, recently appointed by Mr. Webb, includes Dr. Leo Goldberg, Harvard College Observatory; Dr. William A. Sweet, Massachusetts General Hospital; and Dr. Charles Townes, Provost of MIT, the latter being Chairman. Professor R. L. Bisplinghoff, on leave from MIT, is NASA's Associate Administrator for Advanced Research.

But what of the future? What are some of the requirements for keeping pace with space and for further exploiting our skills in innovation and our research-related resources?

There is the need, for example, for more strong centers for graduate study and research in New England.

Every informed study of the Nation's educational requirements for the decade ahead indicates that we must substantially increase the graduate capacity of our university system. This is especially true in science and engineering. In a presidentially endorsed report, the President's Science Advisory Committee recommended in December 1962, that the Nation increase its doctorate output in science, engineering, and mathematics to a total of more than 7,500 per year by 1970, this representing more than a doubling of our present output.

In 1959–60, the output of New England institutions in these fields was just under 400, or 13.7 percent of the national total. If we accept the recommendations of the President's Science Advisory Committee and if New England is to maintain this percentage of the national total, it will have to increase its output of doctor's degrees in science, engineering, and mathematics by 165 percent between now and 1970, or from the present total of approximately 400 to over 1,000 per year. Even if we do not accept an increase of this magnitude, a substantial expansion is clearly essential.

NASA's national fellowship program is designed to increase the number of students pursuing doctoral studies. New England should have no lesser goal than to seek to maintain its present percentage of the total production of doctorate degrees, and in fact its interests would be well served if it could increase its proportion of the total national production.

Of the 40 institutions in the United States giving the most doctorates, there are presently only 4 located in New England. In the years ahead, it will be important to have additional great graduate centers in this region. It is especially important that the region's total output of doctorates in science, engineering, and mathematics be increased by expanded graduate study in institutions other than those which have already expanded their output. You will recall that it was President Kennedy who said, "We need many more graduate centers, and they should be better distributed geographically. New industries increasingly gravitate to, or are innovated by, strong centers of learning and research. The distressed area of the future may well be one which lacks centers of graduate education and research." The growing needs of our technological society as manifested in the space program clearly

declare expanded graduate education to be an important educational goal for New England.

The growing requirement for graduate study is by no means all. Postdoctoral study is growing. Already the number of postdoctoral fellows in the United States exceeds 25,000, most of them in the sciences, medicine, and engineering. The explosion of knowledge makes career-long study a growing necessity for professional men.

By way of example, the rapid emergence of new technologies introduces a much higher rate of professional obsolescence, especially among engineers, applied scientists, and physicians. There are probably many thousands of engineers in the United States who find themselves out of date and who face a reduction in effectiveness unless they can master new fields and technologies not taught when they were in professional schools. This "prevalence of newness" which marks our time poses wholly new demands for education continuing through the practicing life of almost all kinds of professional men.

For example, the recently announced Center for Advanced Engineering Study at MIT is being specifically developed to afford engineers already at work in managerial or research capacities in industry an opportunity to return to college to increase their familiarity with the many areas of science and technology that have emerged since they graduated. It is also designed to equip engineering professors from other universities to expand their programs to the doctoral level.

New England will need more of this kind of "in-service" education.

In stressing these needs in higher education, I do not minimize the equally great needs to strengthen our precollege schools. New England is once again a center of innovation in the teaching process. It was in the Boston area that a national curriculum-reform movement originated. The New England region needs to avail itself of these new advances, especially in the teaching of the sciences, more extensively than it has. We have school systems unmatched in the Nation, but not enough of them if our young people are to be appropriately educated for a period where adaptability to change and higher skills will be increasingly important.

I stress these needs in education in relation to New England's space program because education is my field, but I hasten to emphasize that our success in this region in promoting and maintaining a science-based industry depends upon a coalition of skills and different kinds of institutions.

Drawing upon the jargon of their profession, economists have conceptualized our system of generating, teaching, and distributing knowledge as "the knowledge industry." We have another grouping of activities now under rapid development which might be described as "the innovation industry" and that innovation industry is especially adaptable to our New England environment. To be successful, however, it will require a concert of skills involving bankers, managers, lawyers, engineers, scientists, and entrepreneurs. Education and research cannot alone support the innovation industry.

By better relating industry and education, we can reduce the lag between discovery and application; by reducing tariff barriers among different fields of learning, among institutions, and among the professions, we can cultivate a free trade of brains and skills which can be one of New England's most exciting assets.

One word more. We in this region, both in industry and in education, can best serve the national space program and better strengthen our own economy if our participation comes about because we have something to bring to the national effort that is uniquely helpful, new, and unmatched elsewhere. This means we must be a seedbed of new ideas and a creative resource that the Nation cannot fail to utilize. It may well be that New England has a special and unique role in the use of space for the advancement of science. Our universities are steadily extending their activities, as already mentioned, in astronomy, planetary geology, physiological responses to space, cosmic-ray physics, meteorology, communications, and geophysics in the broadest sense. May there not be an essential industrial counterpart to these developing activities, and may not New England be in a strong position to become a major center for the technology of space science? We have major contributions to make all aspects of space science and technology, but it may well be that the kind of partnership represented in this field would be a natural one for us to exploit.

CONGRESS AND SCIENCE

(Luncheon Meeting)

Chairman
ASA K. KNOWLES
President
Northeastern University

N64-30330

HOW CONGRESS DEALS WITH SCIENCE AND TECHNOLOGY

EMILIO Q. DADDARIO*
Congressman from Connecticut
U. S. House of Representatives

It is a privilege to be asked to tell you how Congress deals with science and technology. As a native of Boston, and a New Englander, I am deeply conscious of the skills and abilities which our area has to offer the Nation, as proven by its role in history, and I am a confirmed believer in its share of the future. I am aware also of the way in which the many applications of science have changed and revivified New England. We all recall the vacuum created when some of our industries moved away, and the struggle to fill that void. I can appreciate your great pride in the strength of New England today without detracting from the fact that much more needs to be done.

First, let us agree on definitions. When I speak of science, I mean the knowledge of physical laws and the natural laws which enables us to assemble all things that should be known in advance of initiating a course of action. Science is, of course, drawn from the Latin word meaning to know. The definition which I have used to refer to knowledge before initiating a course of action is, in fact, the Hoover Commission's definition of intelligence. When we talk about Congress dealing with science and technology we do not refer to a direct encounter. Science is not a subject like agriculture, communications, or transportation, which could be met as a single subject. It appears in most national programs and falls within the scope of many committees.

In its daily work, Congress makes many decisions which affect the course we shall take in seeking to attain our national goals. Most important, we are charged by the Constitution with the allocation of national resources in support of such effort. It is critical that we draw together all our country's resources when we have determined an essential course, and assign them wisely. While management in itself is customarily an executive responsibility, it does not relieve the Congress of the responsibility to review and adjust such action.

The problem which I am discussing has occurred through the remarkable growth of science in this century. Knowledge develops knowledge. It also requires the application of more people and more money to carry on the search for new knowledge. Before World War II, only $300 million a year was spent for research and development in the United States, including Government laboratories and civilian institutions. This year, the Congress has been asked to consider a budget which provides $15.3 billion for research authorized by the Government alone.

The critical importance of the wise use of science in our national future was amply demonstrated by World War II. With its end came the resolve to make better use of science in the ensuing years. Creation of the National Science Foundation was one action intended to further that aim. But as science has been growing and finding new outlets in national policy, the less flexible forms of organization have not always kept pace. Academic organizational patterns have not always adapted to these new issues rapidly. The physical and biological science departments are still very much a part of many colleges of arts and sciences, but the merger and overlap of these fields of knowledge, the sharp need for a recognition of greater study in interdisciplinary fields, has not been met.

Beginning some years ago, the executive branch of the Government made an approach to better organization of science in its work. The President was provided a special assistant for science and technology,

*Chairman, House Subcommittee on Science, Research, and Development.

and the first three times they sought to fill this post, they turned to Boston for expert help.

And now we come to the Congress. The procedures which are followed in the House of Representatives and in the Senate have been developed over many years, and have served the Nation well. They provide for delegation of proposals to the respective committees, the careful and thorough assembly of information which the committee believes pertinent to the subject, study and review, and then recommendations to the full chambers for action.

In this century, subjects of growing complexity have been made the subject of congressional study. Atomic energy is a case in point, and the Joint Committee on Atomic Energy has done a commendable job of dealing with proposals in this area. Many of these proposals involve policy rather than science, and require balance against differing and competing factors before a decision can be made. This is the function which has been the role of Congress over our history.

In recognizing the increase in importance of science, however, it is fair to ask what we have, in a sense, criticized in the universities. Has this importance and its expansion been recognized in more flexible organizational patterns? In all honesty, it cannot be said that the structural lines of the Congress necessarily make for the full use of scientific information. In the mid-fifties, the space program and the possibility of the exploration of space presented a new challenge to the United States. This question was thoroughly reviewed by select committees under the leadership of our present Speaker, John W. McCormack, and our President, Lyndon B. Johnson. We met the challenge by establishing a science committee. The space program which has come under the jurisdiction of that committee has been responsible for one of the most dynamic programs in support of science that the government could have undertaken, but the process of review to see how best it may be used in the national interest goes on.

There have been a great many suggestions about how Congress might strengthen its own sources of information and advice on scientific and technical fields. Our feeling is that it can best be done through the standing committees that now discharge responsibilities in the areas of national affairs and must consider scientific evidence. The membership of staffs for these committees may be strengthened. Temporary consultants may be used, where really technical matters are involved, for whatever period of time is necessary. A mechanism for building up scientific assistance already exists in the Legislative Reference Service of the Library of Congress. It is only common sense that this area can and should be strengthened. Closer liaison with professional societies and industrial organizations has been and is being obtained by our subcommittee and is a fruitful source through which the talents of skilled people may be brought to bear in the mission of Congress.

Our subcommittee has already noted that strong and steady programs of review in highly complex areas are being carried on by standing legislative committees. The Joint Committee on Atomic Energy, the Committee on Interstate and Foreign Commerce in dealing with communications and transportation, and the Committee on Armed Services reviewing changing concepts of weapons, all require and make use of scientific advice. It is important to achieve better liaison among the committees to make the most efficient use of such advice, and to improve channels between Senate and House committees which work on the same problems.

On the science committee, we have created a subcommittee which I chair. This subcommittee has been given the responsibility of exploring the issues raised by scientific research and development across the entire spectrum of the Government.

We began our studies by reference to the full committee's special panel on science and technology, asking the views of the members of this group on the most important questions that affect government and science. Then we began public hearings on the relationship of Federal scientific programs to our national capabilities. Witnesses included many of the Nation's most prominent scientists. From that information, once digested, we have identified major trouble spots in the Government—science relationship, some of the opportunities which exist, and some of the areas which need further study.

Meanwhile, we began publication of essential data for our work. We published a statement of purpose which described a number of technological and social issues as they appear to be crystallizing today. The second report reviewed trends of Federal spending on scientific projects and research. Now in preparation is a preliminary survey of the recently emerged issue of adequate congressional information and advice.

We also approached qualified sources of advice to be of assistance. We have concluded an agreement

with the National Academy of Sciences, the distinguished century-old body of American scientists which, as the late President Kennedy once remarked, through the range and depth of its members, is the seedbed of our Nation's future. We have arranged with the National Science Foundation to report on science education in the country. And we have brought into being a research management advisory panel consisting of highly talented and experienced managers, to help establish useful ground rules which will give us better techniques of choice of programs and for good research management in general, especially in the very costly area of development.

Two problems which have emerged frequently in the discussions which my subcommittee has held have been selected to be the subject of further inquiry next month as another step ahead in our subcommittee's activities. One is the problem of geographical distribution of Federal funds allocated toward the conduct of research and development by grant and by contract. Various actions in other committees of the House have tended to point up this question. It was mentioned with frequency in our hearings. And it was only natural that when Boston was chosen as the site for the Electronics Research Center, the air was blue. But it is much more than local pride that stirred members from other areas—and the thoughts they aroused still hang in the air and need to be analyzed and brought to earth. In part there is the question of whether we are making full use of all the talent across the Nation. Until this question is satisfactorily answered, we cannot be sure that we are making the best use of all our national resources. This is a vitally important issue to our future and deserves serious thought.

For many years, there has been a systematic effort among our geographical regions to encourage greater dissemination of research and educational support to other States. Today, with 100 institutions receiving 9 of every $10 in Federal research funds, and 10 major universities—2 in New England and 2 in California included—receiving 40 percent of the total funds, there is increasing pressure to reexamine this distribution.

This question is more intense than it appears on the surface. The competition for activity, for research, for leadership, and almost inevitably new jobs reaches to the heart of a region's health and well-being. The competition and the battles that can result could be divisive in themselves. The strength of this feeling must not be underestimated.

The second area which the subcommittee proposes to look into is the indirect costs which are, or should be, allowed in connection with Government grants in the field of basic research.

Dr. Nathan Pusey, when he testified before our subcommittee, described this issue as the most serious immediate problem in the universities' relationship with the Government. He reported that it cost Harvard University in 1961–62—the last year for which an approved negotiated rate could be cited—some $668,000 to carry on project research work for the Government.

Perhaps this is somewhat technical, or at least is shorthand for a problem with which we are not all so familiar. The universities are, of course, one of the strongest areas for the conduct of basic research that we have in the United States. This basic research serves many purposes—it produces new information, answers questions that have been raised by the earlier determinations, and assists in an important way the training and education of new men and women in the scientific disciplines. When a university undertakes to carry on a specific project for the Government—or asks to do so, as our system usually requires—it contemplates that the work will be done with its facilities and by some of the great human resources and talent which exist there.

Now this poses a certain conflict of interest within the universities themselves. This, too, bothers a great many educators. To what purpose does a Federal project, admittedly intended to move us close to the establishment of national goals, fulfill the fundamental obligation of the university to teach and lead? Does the immense amount of Federal support of such research, which has grown remarkably in the past decade, tend to warp the university's basic mission? At the same time, the Government and the Congress place certain limitations upon the work, intended to encourage economy and efficiency. What happens when the university, from its scarce scholarship funds, finds itself obliged to divert money to keep laboratory lights burning to help a scientist do Federal work? I have simplified the problem, but I can assure you that any university administrator will be glad to pour forth his woes to you about this drain on university funds to meet indirect costs of research. I know from personal experience—and I agree with them that a better solution is needed, and we hope to help in achieving it.

The National Academy of Sciences, through its Committee on Science and Public Policy, headed by Dr. George B. Kistiakowsky of Harvard, recently filed a report on Federal support of basic research in institutions of higher learning. It has devoted considerable thought to these matters and it has contributed intelligent and constructive suggestions to this area of the Government-science relationship. Again, like Dr. Pusey, the committee concludes that this is one of the most serious fiscal problems to develop in the operation of the project system. And it ably highlights one of the misty areas when it notes that the difficulty of describing indirect costs in accounting terms is precisely what makes these costs indirect.

The Congress has dealt with this problem piecemeal, to this moment, as it has arisen in relation to the research budgets of the varying departments. Thus it has fallen to several committees and subcommittees to make their own determinations. The Appropriations Committee, which I can assure you is always suspicious of anything that looks like an unauditable expense, has devised several formulas, usually expressed in maximum limitations. In the executive branch, where these programs must be administered, the Bureau of the Budget has conducted some detailed studies and approved a circular which is generally agreed to be a fair approach.

Nevertheless, the problem increases in dimension. By statute, varying formulas are being applied. But many universities keep a complete record of their expenditures and find that they far exceed the authorized reimbursement. Indirect costs are incurred for common or joint objectives and are not readily subject to treatment. However, in auditing, wide ranges may develop between universities, and the Congress then tends to approve maximum limitations—such as the 20 percent limit which the House voted recently on research in health areas.

I have sought to indicate that this is a thorny area. Our subcommittee is now preparing to move into the bramblebushes. Some years ago, dealing with the space budget alone, I worked with a subcommittee which went into this problem, and I do not underestimate the difficulties of finding an agreeable solution, one that will provide for research, meet the needs of our educational institutions, and be acceptable to Congress. Our hearings on these two problems are expected to start on May 5, and we will explore first the views of the Federal agencies on these matters.

The program for this conference will give you a great deal of information concerning the promise and prospects for peaceful uses of space. The impact of the Space Age will, of course, continue to be great upon our industry, our economy, our labor force. It is already placing new demands upon education, upon medicine, and upon industrial skills in metallurgy and other technologies.

New England has a great deal to offer in support of this national obligation. I would cite first our great universities, and the fine young men and women whom they send into the world to be leaders in our Nation.

The leadership demonstrated by our universities—Yale, Harvard, Massachusetts Institute of Technology, Wesleyan, Williams, and Amherst, to mention only a few—will be an integral factor in the region's future. MIT's current plans for five new interdisciplinary research centers in the earth sciences, materials, life sciences, communications, and space sciences are extremely interesting and encouraging, and relate directly to the remarks earlier about lagging academic organization. Even before we determine the success of this program we can cite it as direct evidence of university leadership.

I would also cite the traditions and the resources which we have to commit. The Federal Reserve Bank of Boston pointed out in 1959 that in just 5 years of that decade, 85 percent of the total employment gains in expanding New England industries was traceable to six industries that had allocated the largest amounts to research and development. It prophesied that the contributions of research to new employment are bound to secure wider recognition.

In part, this view has been somewhat tempered by time. Research alone does not guarantee the future. There are concurrent problems of information exchange and transfer to product lines. The increasing pace of technology has also been accompanied—perhaps inevitably—by an increasing rate of obsolescence. This basic fact places sober and serious responsibilities on management, and upon the scientists and engineers themselves, to be aware of the rapidly changing frontiers of the state of the art, and to be adaptable to change readily to seize and exploit the new opportunities.

The steps which New England has already taken to assert its leadership in the new technology have stimulated this area's growth and strengthened its

leadership. This is perhaps the greatest reason why so many other areas are anxious to challenge New England for greater participation. Growth, research, and discovery breed further growth.

You have been given some idea of the country's estimate of what the space program alone means to New England and to the country. The other fields which apply to our national goals are also of critical importance. This is a world in which questions which are discussed on Beacon Hill or in Hyde Park may also have tremendous implications to San Francisco or to Paris or Saigon. The pace of change, which has meant much in our lifetime, will mean even more to the generations ahead.

A great many complex and difficult policy decisions, which will affect our future, lie within the responsibility of Congress. This is not unusual; the Congress deals every day with issues that are so intricate they do not receive the full attention of the press or the public. The Congress deals with them in a process which seeks fair and balanced judgments. It is in this spirit that it deals with science and technology.

We are in the midst of a technological revolution, and as in any revolution, the future is uncertain. Perhaps the minimum for which to hope is the reply of the distinguished aristocrat who, when asked what he had done during the French Revolution, answered: "I survived." But there are also the simple facts which can be derived from the expansion of scientific and technological knowledge, considered by many to be the most important element in economic growth. In my discussion of the question of geographical distribution, I have suggested the intense competition for funds and for growth which can be expected from all parts of the country.

The Congress is determined to draw together all the resources of the country, to allocate their use wisely, and to seek the accomplishment, at the earliest moment, of our national goals.

30331

MEN IN SPACE

Chairman
D. Brainerd Holmes
Senior Vice President
Raytheon Company

INTRODUCTION TO MEN IN SPACE

D. BRAINERD HOLMES
Senior Vice President
Raytheon Company

The Space Age is but a little over 6 years old if we consider the beginning to have been the launching of the Russian Sputnik in October of 1957. It is only 3 years since we launched Commander Shepard on his suborbital flight. For many of us it's hard to believe that so much has been accomplished in so short a time—Shepard was followed by Grissom, Glenn, Carpenter, Schirra, and Cooper—all successful manned spaceflights.

At a time when some are speaking of technological plateaux, I am particularly proud to have been asked to be a chairman of a session such as this which is concerned with perhaps the greatest engineering challenge yet to face man. Now, we have but scratched the surface; those of us who saw the launching of our astronauts, felt the shaking of the ground by the initial thrust, and thrilled to the sight of men going into space recognized at that time that we were struggling as man to leave Earth in this great venture that lies before us. Space achievement is of such major proportion as to fire the imaginations of men everywhere and to have an impact, indeed, on world leadership. If anyone doubts that, he has only to talk to those people whose job it was to evaluate world reaction after the flight of that first Sputnik and to evaluate which nations knew—perhaps through the close community of the civilized world, through increased communications, and through being given independence in their own form of government—what nations turned to follow the Soviet Union and their ideology which is so vastly different from ours. To them it appeared at that time that the Soviet were the leaders in space and thus the leaders of technology. Therefore, if we are to stay leaders of the world, if we are to lead the world in our beliefs and our ideology of freedom of man, we must undertake these challenges which become technologically possible.

A great deal of credit should go to our late President John F. Kennedy for his foresight, and for his courage to say for all to hear—his countrymen and all the world—"Now we go to the moon; now we undertake this vast challenge of man going into space." We are fortunate to have with us for this session those Americans who are most directly responsible for the present manned spaceflight program of the United States. I must so qualify it because our present program is the peaceful space program—our military program really has not started as yet in manned space flight.

N64-30331

MAN'S SPACE VENTURE

ROBERT R. GILRUTH
Director
NASA Manned Spacecraft Center

Project Mercury, our initial man-in-space program, represented a "venture" in every sense of the word. It was an undertaking which was definitely speculative in the opinion of many people. Manned space flight ventured forth into a new and unknown physical environment, intellectually into new technologies of engineering and management, and sociologically into a new concept of large-size governmental support of technical development in peacetime without the impetus of war or defense.

It is difficult to discuss the venture of man into space because of the interrelationships of the three types of venturing noted above and because of the concurrent nature of the approaches to the many problems which faced us in this program. This is a review of part of the sociological or political climate that led to the decision to undertake the project, the technological background that permitted us to undertake it, and the problems that we faced in accomplishing the Nation's initial steps in manned space flight.

SOCIOLOGICAL CLIMATE

The United States has historically been in a position of leadership in all types of exploration, and the American people as a group have always had a competitive nature. With the advent of plans for the International Geophysical Year the exploratory and competitive nature of this country led to our planning to launch a small instrumented Earth satellite in order to derive the greatest benefit from this proposed period of new scientific exploration.

The previous leadership of the United States in the field of aviation has been based on continual research and development of means for flying higher, faster, and farther. It seemed only natural to many of us to extend this experience in manned aircraft flight into manned space flight as the next step in the "higher-faster-farther" game.

The relatively unexpected flight of the Soviet Sputnik on October 4, 1957, really sparked the competitive spirit of the Nation. Many groups advanced plans for regaining what appeared to be a loss of national prestige and a loss of our position of world leadership in science and technology. Consideration of these various proposals led the national administration and the Congress to embark on a new era in Federal support of technology. It was determined that the survival of this Nation in the present "Technological Age" depended upon the establishment of a broad capability in engineering and science and that a program of space exploration with relatively large-scale support by the Federal Government was a suitable focal point for this development of capability.

The passage of the National Aeronautics and Space Act of 1958, which established the NASA, was the first major step in this new venture of government into the large-scale development of technology in peacetime. Since this was a first step in a new venture, there were many questions upon which many individuals and groups held opinions but for which no one really knew the answer. Among these questions were:

(1) Just how large should be the Government's investment in such a speculative undertaking?

(2) What should be the division of effort between the manned and unmanned phases of this exploration?

(3) What should be the division of effort between the peaceful and the military or defense aspects of the program?

In the area of financial support, the space program started small in order to minimize the risk of potential waste. The support was built up as we learned what

was needed, and it now appears to be approaching a leveling-off point. In the areas of "peaceful vs. military" and "manned vs. unmanned" efforts the problems, and the answers, have been rather intertwined. Since the capabilities of man in a space-flight environment were unknown, it appeared wise to devote part of the peaceful program to a determination of these capabilities before embarking on a military program to utilize these capabilities for national defense. In the unmanned program the differences between the civilian scientific and military defense applications were not easily visualized, and thus simultaneous "peaceful" and "military" programs were undertaken. The result of our experience has led us to a situation at present where the answers seem to be, as shown in figure 1:

(1) The total financial support is leveling off at about 7.5 to 8 billion dollars per year, just over 1 percent of our gross national product.

(2) The manned program is receiving about one-half of the total support.

(3) The civilian and military share about equally in the unmanned effort, and a military-manned program now seems to be getting underway.

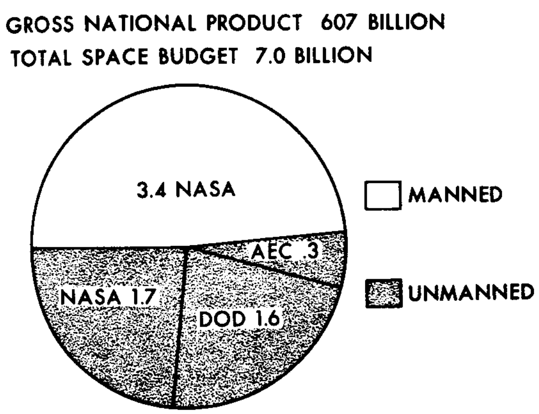

FIGURE 1.—Space budget for fiscal year 1964.

Thus we can see that the past 6 years of experience have developed partial answers to these questions, but the inherent lack of answers in the early days of the program did pose problems.

TECHNOLOGICAL BACKGROUND

Figure 2 shows a general outline of the development of the technological background that made it possible for this country to undertake a manned space-flight program. The research and development capacity of this country during the past several decades has lain in the basic research establishments like NACA and the universities, in the armed services, and in the industry. The primary contributions of each of these elements is listed on the left in figure 2. The application of these contributions was, up until 1958, devoted primarily to two areas: aircraft and missiles. The development of these two classes of vehicles produced technical knowledge in the disciplines shown in the center of figure 2. As indicated in the figure, the combined knowledge in these two areas resulted in the overall technical basis for manned space flight.

Some of the more specific items in this buildup of capability indicate some of the problems we faced.

REENTRY HEATING

One of the major new problems posed by the missile and space age was that of thermal protection of a vehicle during its reentry into the atmosphere from the high altitudes and high speeds associated with intercontinental-range ballistic missiles. H. J. Allen of the NACA Ames Aeronautical Laboratory proposed that the basic answer to this question lay in the use of very blunt high-drag reentry bodies. With such bodies most of the high kinetic and potential energy could be dissipated in the form of shock-wave drag, which heats the air, and only a small fraction is dissipated as skin-friction drag, which heats the body.

Various proposals were advanced for coping with the amount of heat that could go into the body. Among these were (1) the use of heat sinks, wherein the body material has a high enough heat capacity to absorb the thermal energy without melting; (2) the use of transpiration cooling, wherein a liquid or gas is ejected from the body into the boundary layer to prevent much of the heat from entering the body; and (3) the use of ablation, wherein the melting or decomposition of a thin layer of the body surface absorbs heat (as does the heat sink) and also the molten or decomposed material flows into the boundary layer and blocks part of the heat (as does transpiration cooling). The first and third methods were developed in ground and flight tests by the Air Force and the Army, and by the time Project Mercury was ready for serious consideration, the feasibility of both methods had been demonstrated.

The remaining questions then concerned such mat-

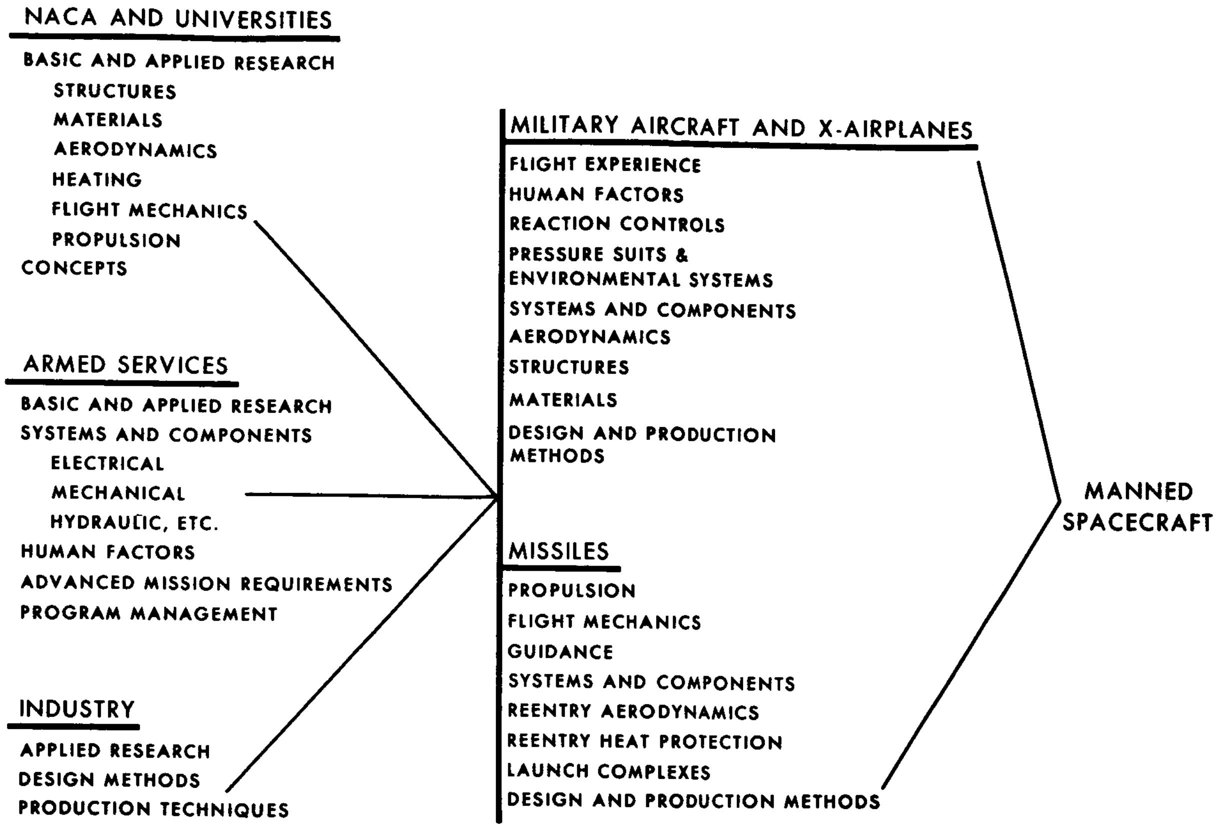

FIGURE 2.—Spacecraft development.

ters as material selection, fabrication techniques, structural design techniques, and weight trade-offs. These were answered by the design and development phases of Project Mercury.

REENTRY LOADS

Another example of technological problems of early manned space-flight planning is the question of reentry loads. Some of the first studies made in this area were based on a ground rule that the pilot should never be subjected to more than 12g of acceleration. This was based on aircraft flight experience with seated pilots. The earliest solution proposed was to use a lifting reentry body, which would inherently be heavier than a ballistic body and would thus require either that an extra stage of propulsion be added to the Atlas ICBM or that the program be delayed until a more powerful launch vehicle became available. The final solution, the one actually used in Mercury, was to use the Faget contoured couch which permitted the pilot to withstand safely the higher loads inherent in the ballistic design.

PROGRAM HISTORY

Preapproval Era

Prior to October 1958, when Project Mercury was officially started, a great deal of study effort was expended by various groups to define an adequate first step in a manned-space-flight program. Concurrent and independent (but coordinated) studies by the NACA, Air Force, Army, Navy, and ARPA culminated in the formation of a Joint Manned Satellite Panel by NACA and ARPA in the fall of 1958. This panel collected the results of the various studies and proposed to the Director of ARPA and the newly appointed Administrator of NASA a program that was accepted and approved in early October 1958. The program was as follows.

The initial approach to manned space flight should have two major objectives:

(1) Achieve manned Earth-orbital flight and recovery.

(2) Determine man's capabilities in a space-flight environment and in those environments to which he

would be subject upon going into and returning from space.

These basic principles should be adhered to in the project. These were the use of:

(1) The simplest and most reliable approach
(2) A minimum of new developments
(3) A progressive buildup of tests

The basic method for accomplishing the project should be the use of:

(1) A high-drag reentry vehicle
(2) An ICBM for the launch vehicle
(3) Retrorockets for initiating reentry
(4) A parachute descent after reentry
(5) An escape system to remove the spacecraft from the vicinity of a malfunctioning launch vehicle.

The above basic objectives, principles, and method initially established for Project Mercury have remained essentially unchanged throughout the life of the project.

Immediate Postapproval Era

On October 7, 1958, we were faced with an enormous task for which we were fairly well prepared technologically but relatively unprepared in organization, management, funding, schedule, and policy. We thus had to face immediately the problems in these many areas as well as the detailed technical problems.

Because of the unsettled nature of national policy during the year between Sputnik I and the official start of Mercury, the funds available for beginning such a program were limited. However, we were able to begin. Upon approval of the program, a multipronged effort began to:

(1) Define spacecraft specifications
(2) Select a spacecraft contractor
(3) Define launch-vehicle requirements
(4) Arrange for the launch vehicles to be supplied (Atlas by USAF, Redstone by Army, and Little Joe by NASA; see fig. 3)

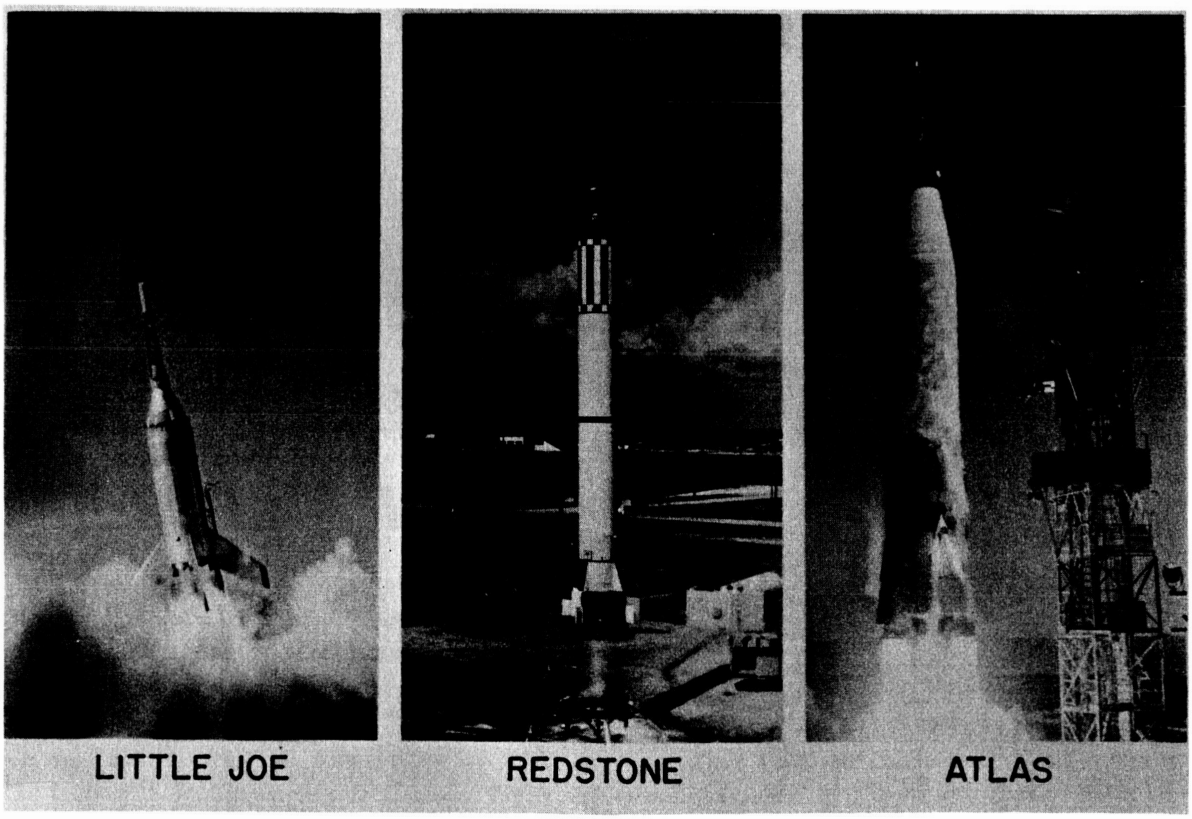

FIGURE 3.—Project Mercury launch vehicles.

(5) Build up a management organization
(6) Define mission and network requirements
(7) Select and train astronauts

Manufacturing and Development Period

The first year of the program, which covered the immediate postapproval era and the first half-year of the manufacturing and development period, saw the buildup of a management staff and the outlining of program, schedule, and budget through better definition of the job to be accomplished. The program was well enough defined by early in 1960 to allow estimates of cost and schedule that were very close to the final numbers.

The second year of the program, 1960, saw the appearance and solution of many of the technical hardware problems in the spacecraft and launch-vehicle systems. These problems appeared when detailed design, manufacturing, and test efforts showed that the state of the art in many systems such as parachutes, electrical power systems, electronics and so on, had not advanced as much as we had hoped. In fact, this advancement of the state of technology is one of the primary reasons for the whole space program—simply the need to make this Nation strong in all ways.

This second year of Project Mercury also saw the development of a set of functional relationships among the various Government and industry groups involved in Mercury. These relationships are shown in figure 4. This chart illustrates the complex nature of such a program and the large number of diverse groups whose talents must be drawn together to carry out successfully a manned space flight. These relationships have evolved and changed in detail during the past several years, but the basic pattern and spirit of cooperation have remained.

Program Growth Period

The birth of the present manned-lunar-landing program was another product of the 1960-61 period.

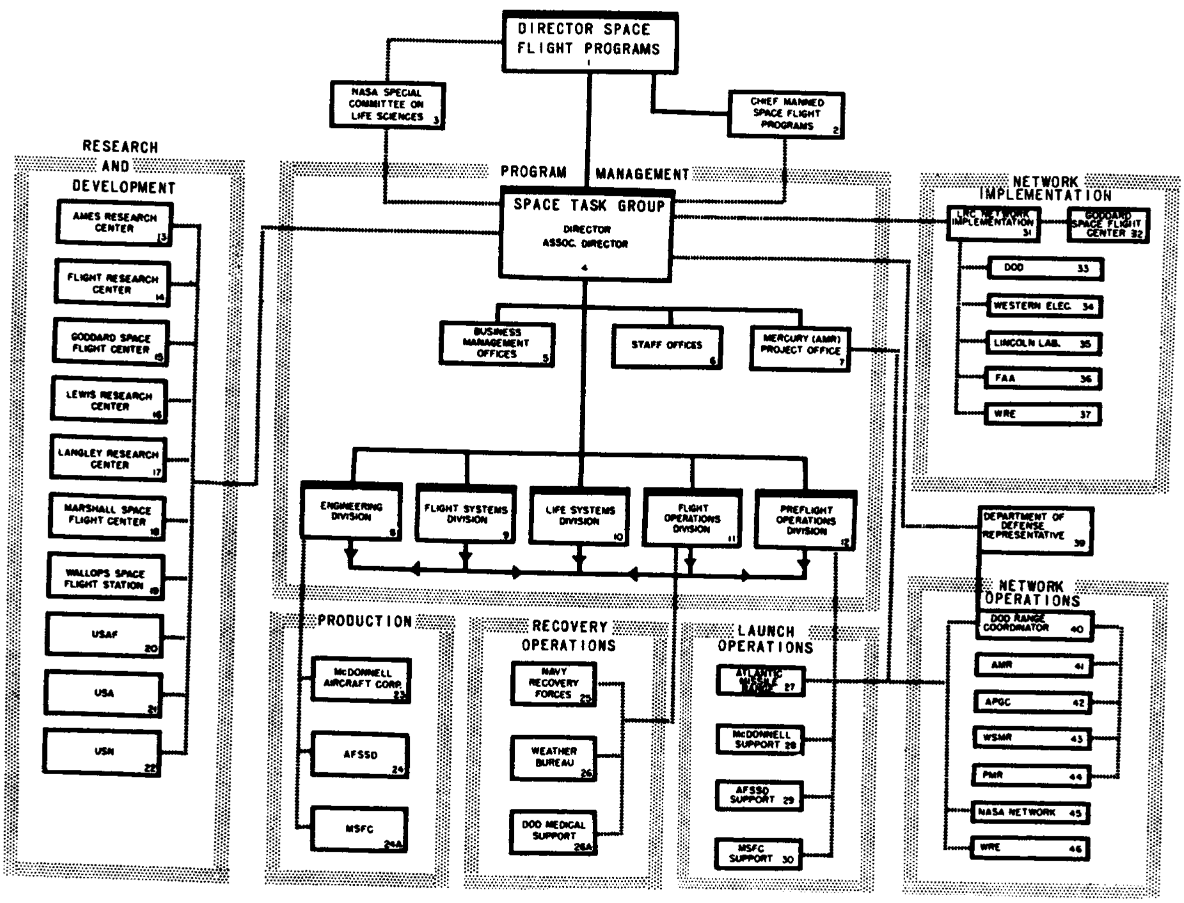

FIGURE 4.—Project Mercury functional relationships.

A study directed toward establishing our next major goals in manned space flight beyond Mercury indicated that a system which included a small Earth-orbiting laboratory and which was capable of circumlunar flight represented a step that was both significant and within the expected rate of development of our technology. During 1960 a research program was undertaken within NASA, and a design study and development program was started within industry, to better define the Apollo system and its capabilities.

Following Alan Shepard's flight on the Mercury-Redstone, the decision was made that the Apollo program would be focused on a manned lunar landing and return within the decade. Other events of the year were the decision to undertake Project Gemini as a step between Projects Mercury and Apollo.

Apollo, which will be discussed in more detail in subsequent papers, requires a really major step beyond Mercury in manned-space-flight technology. Requirements for mission control are as follows:

Mercury	*Apollo*
Up to 1 day	7 days
No maneuvering	Maneuvering
Near-Earth tracking	Near-Earth and deep-space tracking
Simple computing	Complex computing
Ballistic reentry	Reentry control
Recovery control	Recovery control
Training	Training

There is a marked increase in flight duration, maneuvering in space, more complex tracking and computing, and reentry control of a maneuverable spacecraft. All of these differences are accompanied by more complex spacecraft systems and hardware. The size of this step is a basic reason for the Gemini Project. Gemini will give us an intermediate task upon which we can focus to gain lead time in many of these technical areas. The Gemini spacecraft, for example, is larger than the Mercury (fig. 5) in order to carry two men and extra supplies to allow us to gain expe-

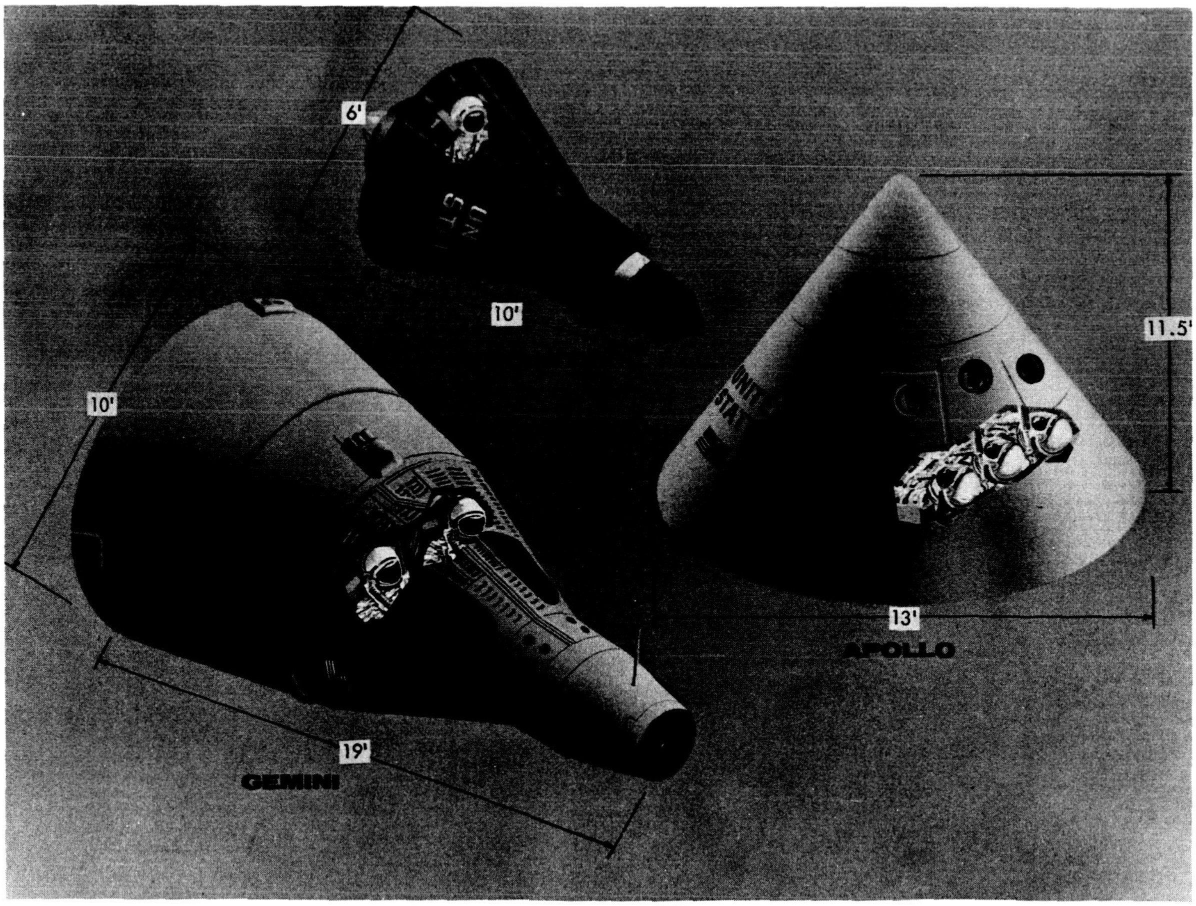

FIGURE 5.—Comparison of manned spacecraft.

rience with long-duration flights. Like Apollo, Gemini will have advanced navigation and control equipment to permit both space and reentry maneuvering. The Gemini mission objectives are as follows:

(1) Preflight checkout techniques
(2) Time-critical launch
(3) Variable launch azimuth
(4) Onboard guidance
(5) In-flight maneuvering (rendezvous and docking)
(6) Long-duration manned flights
(7) Advanced ground-control techniques
(8) Controlled lifting reentry
(9) More complex recovery
(10) Flight-crew training
(11) Ground-crew training

With Project Gemini we will be gaining experience and developing technology that will apply to the Apollo mission. The long-duration flights will give us a chance to exercise men and equipment for long periods of weightlessness in a space environment but close enough to Earth for return, in an emergency, within minutes or hours rather than days. The rendezvous exercises will permit us to develop optimum manual or automatic techniques of bringing two spacecraft together before we are committed to its actual use in the Apollo lunar orbit rendezvous. The use of such advanced systems as hypergolic-fuel reaction controls, onboard guidance computers, and fuel-cell batteries will allow us to learn and solve the problems with this type of equipment before the Apollo preflight schedule becomes critical.

Like 1961, 1962 saw us engaged in many concurrent efforts:

(1) The establishment of the Manned Spacecraft Center in temporary quarters in Houston

(2) The design and start of construction of the permanent Center facilities

(3) John Glenn's orbital flight, followed by those of Carpenter and Schirra

(4) The selection of contractors for the Lunar Excursion Module

(5) The various Saturn V stages

(6) The establishment of the Launch Operations Center (now John F. Kennedy Space Center, NASA) in Florida

(7) Continued design and fabrication of the Mercury, Gemini, and Apollo space vehicles

Going on into 1963, the fifth year, we saw the completion of Project Mercury with Gordon Cooper's highly successful 22-orbit flight, the continuation of detailed design, development, and fabrication efforts on Apollo hardware, and the extremely satisfactory series of successful flights of the Saturn I vehicle which will be used in early Apollo development flight tests and which has laid the groundwork for the design concepts of the Saturn V.

This year of 1964 has begun well. We have made our major move into the new Manned Spacecraft Center facilities; we have made a successful first flight of the Gemini space vehicle; the design of the Lunar Excursion Module has been established; and significant progress has been made in both the design, development, and fabrication of the Apollo space-vehicle system and in the ground facilities in Mississippi and Florida. We are looking forward to further flights of the Gemini this year and to an important series of flight tests of Apollo spacecraft and Saturn hardware during the year.

N64-30332

MAN'S EXPLORATION OF SPACE

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Dr. Gilruth's presentations traced the origins of our manned space program, and Dr. Mueller's, the path upon which we have firmly placed our feet. In preparing this paper, which attempts to describe the development of the Apollo spacecraft, I was reminded of a *New Yorker* cartoon of several years ago. The scene was ancient Egypt, during the period when the Pharaohs were taking advantage of the latest scientific breakthrough to erect their new monuments. At the foot of a half-completed pyramid, a train of hundreds of workers was pulling one of the large stones into place under the baleful eye of the construction foreman, dutifully outfitted with hard hat and whip. In the traces, one of the laborers was saying to his partner, who had obviously been grumbling, " Stop your complaining. Don't you realize that it's a privilege to be associated with a project this vast?"

The Apollo spacecraft are the apex of the lunar program pyramid—the top 90 feet of the 375-foot-high vehicle which some day in this decade will rise majestically from the pad at Cape Kennedy, propelling three of our more adventurous citizens to their historic rendezvous with the Moon.

There are today over 130,000 Americans laboring "in the traces" to make this dream a reality. Although the goal of the program provides an overlay of glamour, the work is the same type of hard, detailed, technical development task which we have been tackling in this country to meet defense or space goals over the last three decades.

The main difference comes from the fact that the space environment, coupled with the demands of the lunar mission, is terribly unforgiving. Any design or quality deficiency in the spacecraft or any of its subsystems will be sure to appear some time during the 2-week mission, causing, at the very least, an abort, and, at the worst, tragedy. Although we have provided redundant backup for critical systems aboard the spacecraft, our emphasis is on developing each system to the point where it will not malfunction. Fortunately, the Space Age has matured to the stage where we understand the environment; we understand how to design to meet it; we understand how to test in our Earth-bound laboratories to determine deficiencies which otherwise would be found during flight tests.

This maturing of our understanding has shaped our entire program. The lunar effort began in 1961. The first major contract awarded was to the Instrumentation Laboratory at Massachusetts Institute of Technology (MIT) for development of the guidance and navigation system. In December of that year, North American Aviation, Inc., was awarded development of the command and service modules. Almost a year later, the lunar orbit rendezvous approach to the overall mission was selected, and Grumman was brought onto the team to develop the lunar excursion module. Almost a year and a half of detailed study had been devoted to defining the mission and developing the specifications for the necessary system elements.

The development program has proceeded with similar deliberation. The command and service modules, and their subsystems, have been in design and developmental test for almost 2½ years. The fruits of this effort are just beginning to ripen. Last month the first functional Apollo guidance system was qualified in Cambridge, Mass. In May the launch escape system and the Earth landing system will be tested under flight conditions with a *boilerplate* spacecraft at White Sands. A few days later, a command and

service module, again of boilerplate construction, will be launched from Cape Kennedy atop a Saturn I to check our calculations of the aerodynamic loads which will be encountered during launch. These two flight tests mark the gradual transition of the program from the developmental phase, where we work out the early design problems, to the qualification phase where we prove that the design is indeed worthy of flight. The focus is the first launch of a complete command service module aboard a Saturn IB early in 1966.

If there is any one thing that sets the manned space flight program apart from other, apparently similar, development programs, it is the rigor with which we execute the ground test program. The guidelines we use are simple:

1. Test hardware as early as possible.
2. Make procedures rigorous.
3. Provide consistent test plans and procedures.
4. Provide responsive malfunction investigations.
5. Provide accurate configuration control.
6. Conduct test readiness review.
7. Analyze results; report concisely and quickly.
8. No testing with unresolved anomalies.

In a way, these guidelines sound like a litany of good generalizations, but we take them literally. Every failure encountered in ground testing must be understood and corrected before the spacecraft is certified for flight. This program discipline—the refusal to shoot and hope—should make our flight tests demonstrations of the fact that we have solved our problems on the ground. The only failures which should be encountered in flight are those which can arise from a combination of environments which we were unable to simulate in our laboratories. Since there are still several such conditions, we cannot expect a perfect record—but the success ratio should be relatively high.

The flow of the overall program is shown in figure 1 The early command (CM) and service modules (SM) are injected into earth orbit by a Saturn IB to certify the spacecraft and work out crew operations for periods up to 14 days. About a year later, the lunar excursion module (LEM) is added to the stack for its initial flight test. Subsequent tests will work out the rendezvous procedures between the two spacecraft and simulate the lunar mission without ever leaving Earth orbit.

These tests will take place at the same time that the Saturn V, the massive vehicle required to place the fully fueled spacecraft on the trajectory to the Moon, is being developed and flight tested. Thus the parallel testing paths will provide a spacecraft and booster which, when mated, will be ready to consummate the lunar mission.

One of these national conferences would not be complete without at least a brief description of that mission. Since last year we have concentrated on filling in the detail around the nominal lunar orbit rendezvous mode. Since the Earth–Moon geometry varies continuously, many trajectories must be developed in our computers to be sure that all essential conditions can be covered by our design.

The particular trajectory shown in figures 2 to 4 is for May 6, 1968. (This is not an announcement of intent, merely an example.) For operational reasons we wish the launch and Earth landing to take place during daylight, and the lunar landing to occur

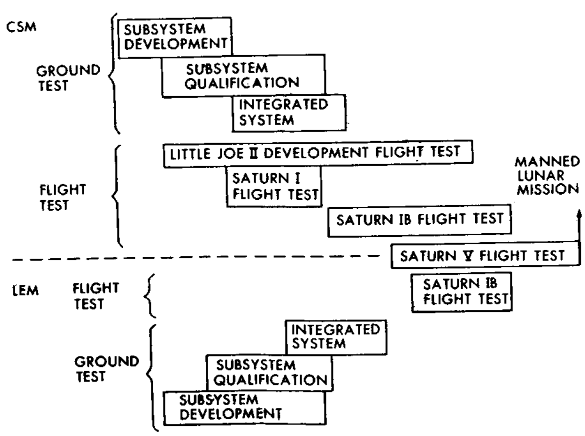

FIGURE 1.—Apollo spacecraft test program.

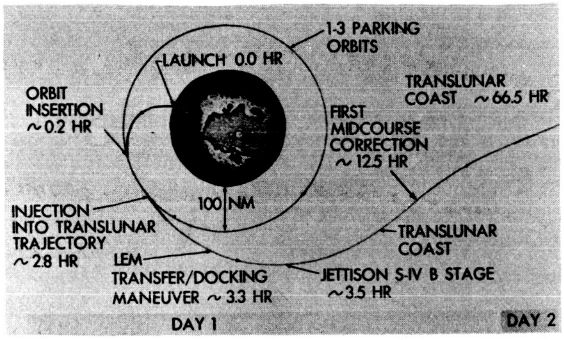

FIGURE 2.—Earth launch phase of typical lunar mission profile.

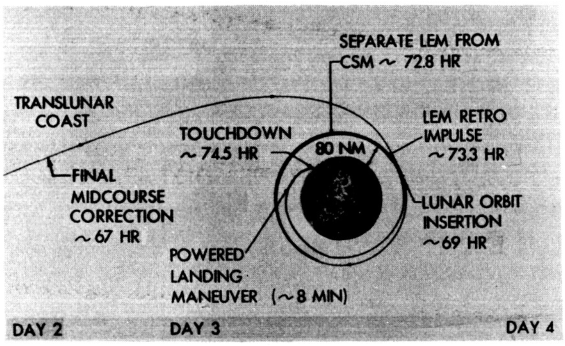

FIGURE 3.—Lunar landing phase of typical lunar mission profile.

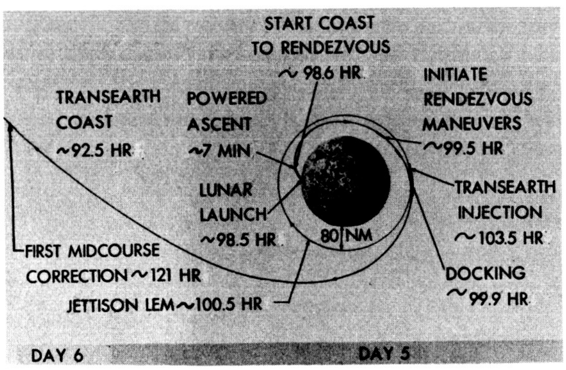

FIGURE 4.—Lunar launch phase of typical lunar mission profile.

when the Sun is 45 degrees above the lunar horizon, to provide optimum lighting conditions for control of touchdown. Table I is a possible schedule of another possible mission.

TABLE I.—*Mission Schedule*

May	Day	Cape time	
15	Monday	1:32 p.m.	Launch: pad A, complex 39, 72° launch azimuth. Had 2½-hr launch window but made it right on nominal time. Translunar trajectory <18° relative to Moon orbital plane. 12 min to orbit.
		3:50 p.m.	Docking completed
16	Tuesday	1:00 a.m.	First midcourse.
18	Thursday	7:30 a.m.	Final midcourse.
		9:30 a.m.	Lunar orbit insertion behind Moon.
		1:50 p.m.	LEM retro.
		3:02 p.m.	Lunar touchdown.
19	Friday	3:02 p.m.	Lunar launch.
		4:02 p.m.	Rendezvous behind Moon.
		8:02 p.m.	Trans-Earth injection behind Moon.
20	Saturday	1:30 p.m.	First midcourse.
23	Tuesday	2:02 p.m.	Final midcourse.
		4:02 p.m.	Jettison service module.
		4:38 p.m.	Parachute deploy.
		4:50 p.m.	Touchdown in Pacific at 12:50 p.m. Honolulu time.

FIGURE 5.—Suggested lunar landing areas.

Figure 5 is a map of possible lunar landing areas. The lunar landing site was arbitrarily selected, but represents the gneral area in which we can expect to explore. Later missions may stay somewhat longer than 24 hours on the Moon's surface, and up to 7 days in lunar orbit.

The Earth landing area will, in general, be the Pacific Ocean. On this particular mission it is about 400 nautical miles north east of Hawaii. The exact point of touchdown will depend on the exact mission flown and the other constraints placed on the flight.

In summary, much has been accomplished since 1961—much more must yet occur before the command module splashes down, still warm from its triumphant reentry. Important as that splash will be, in a sense, it will be an anticlimax. As Havelock Ellis said once, about philosophy, "It is not the attainment of goals that matters; it is the things that are met with on the way." On the way to the Moon we will meet, and solve, all the problems which stand between us and mastery of space. The heritage of the lunar program will not be merely the lunar rock we bring back, but rather the Apollo space ships and launch vehicles, coupled with a broad-based national team capable of coping with any and all requirements for operations in space which may be thrust upon this Nation.

The past year has seen much progress in the development of the spacecraft. We are on the schedule and within the budget discussed at this conference last year. We hope to be able to report increasing accomplishment within those same two constraints next year and each succeeding year until, in 1970, we can, as Dr. Gilruth did with Mercury, summarize how it was done.

N64-30333

MAN'S TRANSPORTATION TO SPACE

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As an introduction, the three launch vehicles of the Saturn class, namely, Saturn I, Saturn IB, and Saturn V, will be described briefly. They are being developed by NASA for extension and increase of the space-flight capability of the United States in general and for the Apollo program in particular. Although the Titan II in its application as a launch vehicle for the Gemini program and the Atlas Centaur for the Surveyor program and other possible scientific uses, can be considered as large-launch vehicles, we will concentrate on the Saturns.

Figure 1 shows all three Saturns in their configurations with payloads for the Apollo program. The following data are rounded to present an idea of the size of the Saturn vehicles.

The Saturn I, on the right in figure 1, is a two-

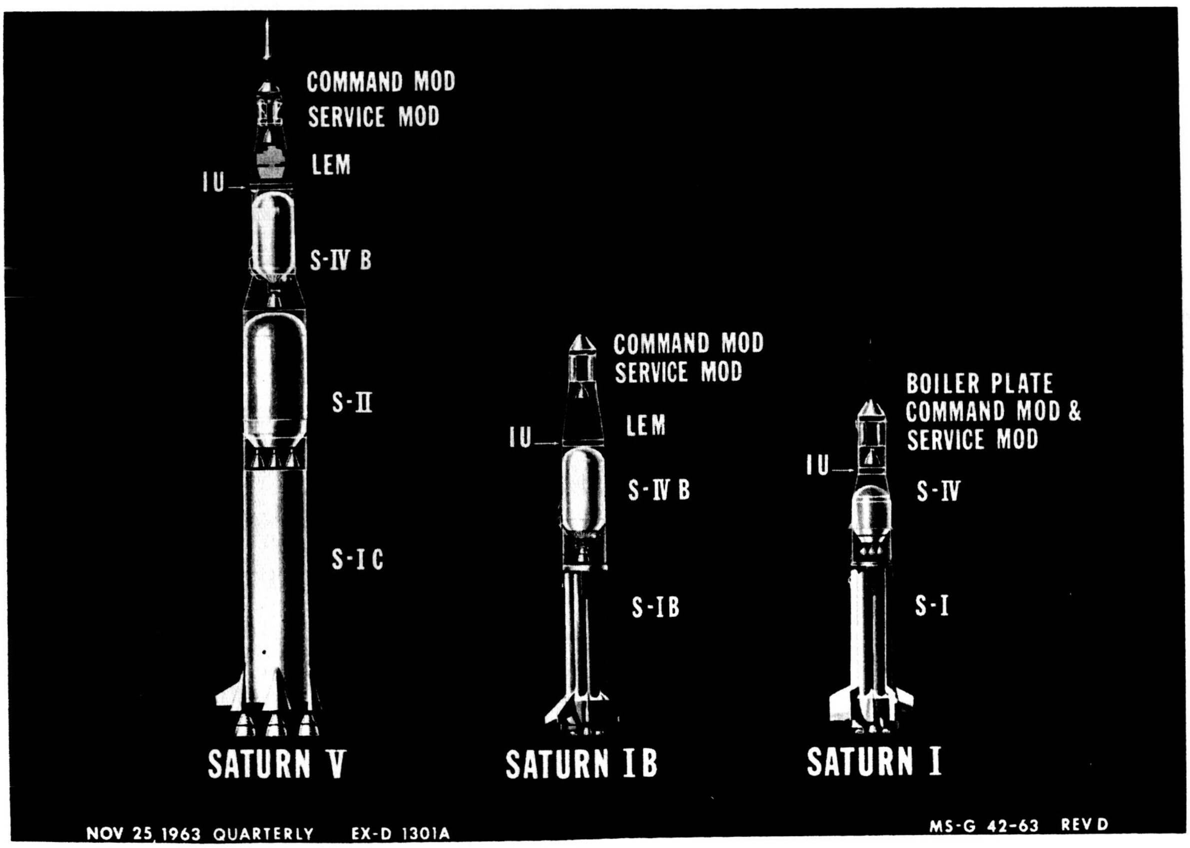

FIGURE 1.—Saturn vehicles for Apollo.

stage vehicle. Its total length, including the payload, is 190 feet. The length of the launch vehicle, itself, including the instrument unit (IU), is 126 feet. The takeoff weight of the launch vehicle is approximately 1,125,000 pounds, of which 950,000 pounds are propellants. The Saturn I is capable of placing a payload of 22,000 pounds in a 100-mile orbit.

The Saturn IB, as depicted here for its Apollo mission, is also a two-stage vehicle with a total length, including payload, of 224 feet. For the launch vehicle, including the IU, the length is 141.6 feet and the takeoff weight is 1,240,000 pounds, of which 1,120,000 pounds is propellants. The Saturn IB is able to place a payload of 32,500 pounds in a 100-mile orbit. For missions other than Apollo we are considering a third stage, which will be discussed later.

The three-stage Saturn V in its present configuration is optimized for the Apollo program. It is capable of injecting a payload of 90,000 pounds into a lunar trajectory. It could also carry approximately 240,000 pounds of payload into a 100-mile Earth orbit. The length of the total vehicle, including payload for the three-man landing on the Moon, is 360 feet. The launch vehicle, with the IU, is 281 feet in length and at takeoff weighs 6 million pounds, which includes 5.5 million pounds of propellants.

As can be seen in figure 1, we adhere to some extent to the building-block concept. The first stage of the Saturn I—that is, the S–I—appears with some small modification as the S–IB first stage of the Saturn IB launch vehicle. Both stages are clusters of eight H–1 engines. These modifications are mainly in the areas of lowering the structural weight and in obtaining higher engine performance. Therefore, the overall performance of the S–IB is better than that of the S–I. We also incorporate into the S–IB as improvements whatever we learn from the S–I development, insofar as the time schedule permits. The S–I and S–IB are being produced under a prime contract with the Chrysler Corporation's Space Division at the Government-owned Michoud Plant in Louisiana. The H–1 engines are produced by the Rocketdyne Division of North American Aviation. The propellants are kerosene and liquid oxygen.

There is somewhat greater difference between the S–IV stage, which is the second stage of the Saturn I, and the S–IVB stage, which is the second stage of Saturn IB. The S–IV has a small diameter, is shorter, and has six Pratt & Whitney RL–10 engines which provide total thrust of 90,000 pounds; whereas the S–IVB is propelled by one J–2 Rocketdyne engine of 200,000 pounds thrust, using liquid hydrogen and liquid oxygen as propellants. However, the principal structural design, the material, the insulation concept of the hydrogen tanks, the manufacturing methods, tooling concepts, and many other features are exactly the same. Again, in the development of S–IVB we are utilizing all the knowledge and experience gained from the S–IV. The prime contractor is Douglas Aircraft. The S–IVB stage also is the third stage of the Saturn V.

The instrument unit, called the IU, contains all equipment to guide and part of the equipment to control the launch vehicle up to insertion point, or in the Saturn V to injection point. It also contains such items as power supply, power distribution, certain telemetry equipment, command receivers, and tracking transponders. This instrument unit on the Saturn IB is quite different in design from the one used on the Saturn I. However, a number of guidance and control devices—for instance, the stabilized platform—are being tried on the Saturn I and then used on the Saturn IB and Saturn V. However, the IU's on the Saturn IB and Saturn V are the same. Of course, settings on instruments are sometimes different from individual launching to launching, depending on the various missions. The prime contractor for the IU is International Business Machines, IBM.

The S–IC first stage of the Saturn V is under development and production by Boeing's Launch Systems Branch at Michoud, La. It is propelled by the largest kerosene/liquid oxygen engine, the F–1, which produces a thrust equal to all eight engines of the Saturn I. In the S–IC, five F–1 engines are used in a cluster to yield a total of 7.5 million pounds of thrust. This engine is a product of the Rocketdyne Division of North American Aviation, NAA.

The S–II second stage of the Saturn V, a liquid hydrogen/liquid oxygen stage, is under contract with the Space and Information Division of NAA at Downey and Seal Beach, Cal. A cluster of five J–2 engines with a total thrust of 1 million pounds propels this stage; thus the J–2, like the H–1, is used as a common engine for two stages.

Figure 2 shows the S–IC stage, mentioned earlier, with the two separate propellant tanks, the engine arrangement, the heat shield, the thrust frame, the propellant lines, and the interstages. The length is 138 feet, and the diameter is 33 feet. During the

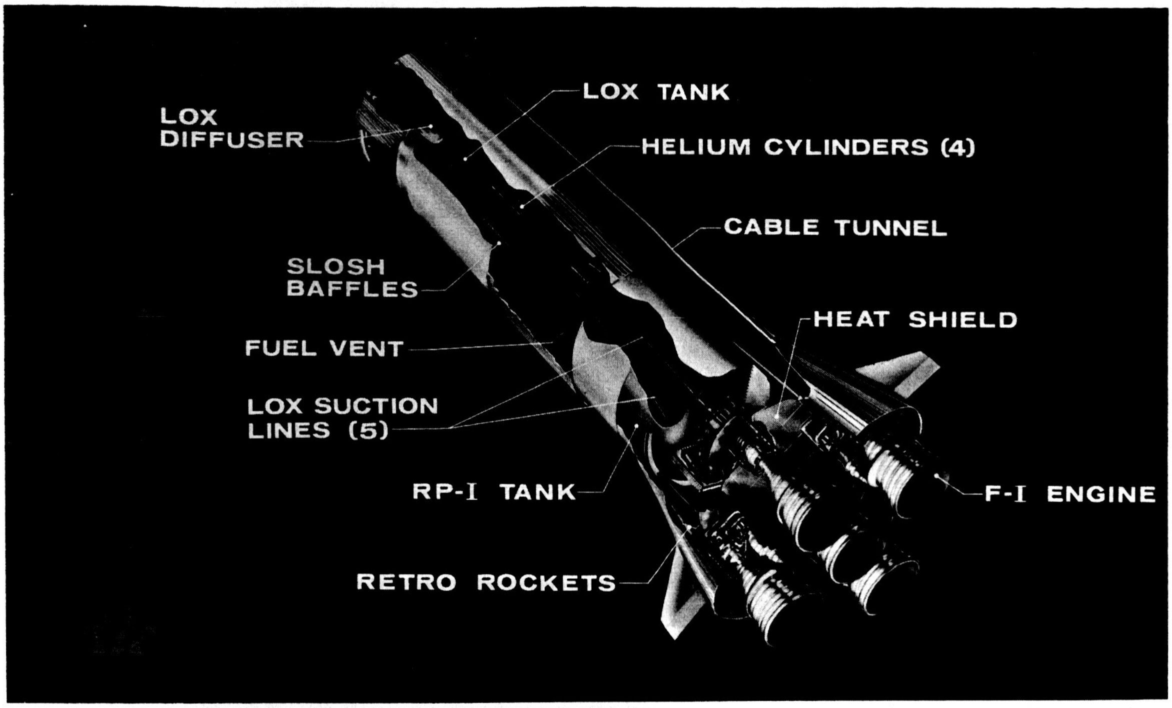

FIGURE 2.—S–IC stage.

burning time of 150 seconds, more than 4 million pounds of propellants are consumed. When this stage cuts off, the Saturn V space vehicle has attained a velocity of approximately 7,000 feet/second—almost 5,000 miles/hour. The stage is then dropped.

The initial static testing for development and for acceptance of the stage will be performed at Huntsville. Later, testing will take place at the large Mississippi Test Facility near Michoud.

Figure 3 depicts the S–II stage. The liquid hydrogen and the liquid oxygen tanks are separated by a common bulkhead. This is a challenging assignment in manufacturing but provides considerable savings in weight. The engines are arranged with the inner engine mounted in fixed position, and the outer four engines can be deflected by hydraulic actuators to control the vehicle in pitch, yaw, and roll as is done on S–IC stage. During the S–II burning time of approximately 390 seconds, about 920,000 pounds of propellants are consumed. When this stage cuts off, the Saturn V vehicle has attained a velocity of approximately 20,000 feet/second, almost 14,000 miles/hour.

The four types of engines utilized in the Saturn launch vehicle program are shown in figure 4. As noted earlier, the F–1 is used in the S–IC first stage of the Saturn V. The J–2 is used in the S–II second stage of the Saturn V and in the S–IVB, which serves as the third stage of the Saturn V and the second stage of the Saturn IB. The H–1 serves in the S–I and S–IB first stages of the Saturn I and the Saturn IB. The RL–10 serves in the second stage of Saturn I and in the upper stage of the Centaur.

A few of the major considerations which guide the current Saturn launch vehicle program are:

1. Building block concept
2. Extensive test and quality assurance program on the ground
3. Systems engineering
4. All-up concept

The building block concept is considered a vital element in the program since it saves time and money, helps build up experience and knowledge, and will contribute considerably to the reliability.

An extensive test and quality assurance program on the ground is necessary because of the extreme technical complexity of each system, subsystem, and

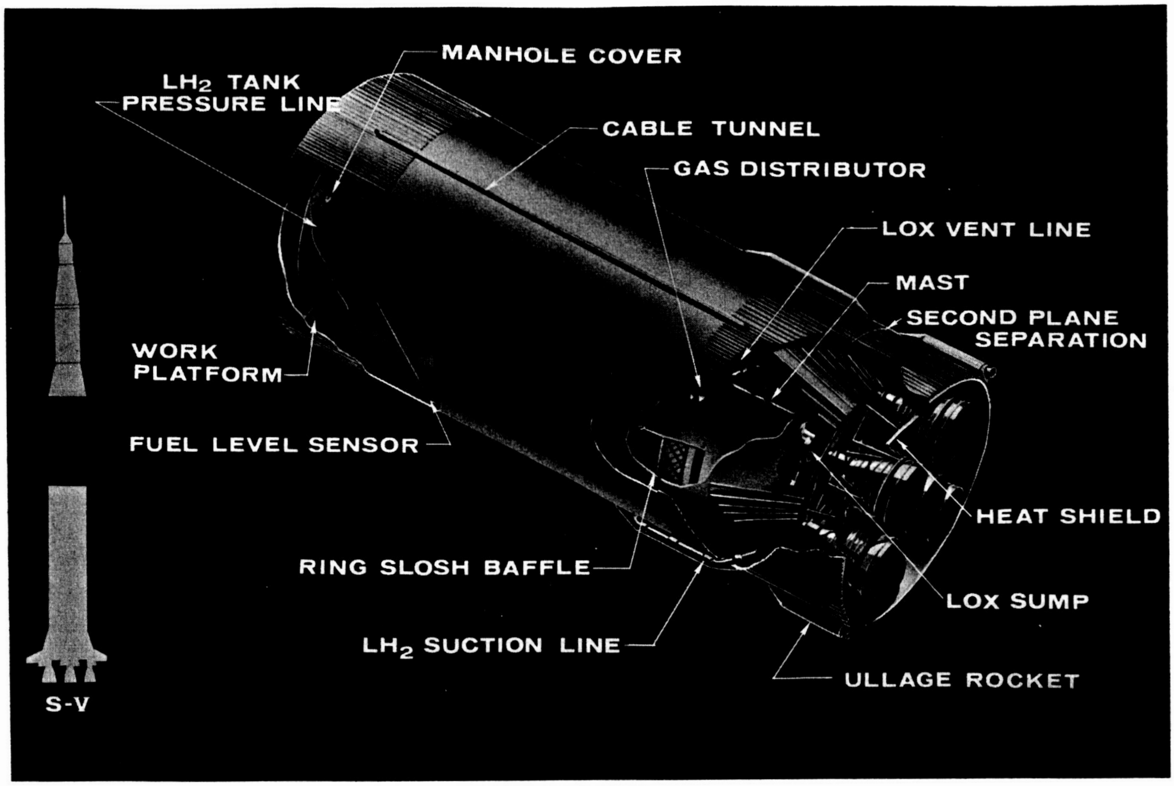

FIGURE 3.—S–II stage.

component—as well as the small number of launch vehicles planned for development. In the development of guided missiles for weapons systems it was found expedient to plan for quite a number of launchings to prove such matters as design, performance, accuracy, and reliability. Only after a launch program of this magnitude had been conducted successfully could the military services feel assured that they could declare the vehicle operational for troop use.

This approach in the Saturn launch-vehicle development is completely impracticable because the conduct of such a program would cost an excessive amount of money and time. NASA must therefore restrict itself to very few launchings for the development of the vehicle. Although the primary mission of these few launchings is the development of the launch vehicle, it is necessary to carry some payload in the early phase of development to get maximum benefits from these expensive undertakings. This is especially true with respect to the Saturn V. Therefore, we must have the highest possible confidence that each and every launching is successful.

This needed assurance can be obtained only by conducting a very thorough test, quality assurance, and reliability program at the NASA Centers, at the prime contractors' plants, and at their subvendors' plants on systems, subsystems, components, and vital parts.

The urgent necessity of such a program is emphasized by the fact that the Saturn IB and V will have to transport astronauts. Man rating requires the highest possible reliability of all systems, and this in turn must be assured by these few launchings. It will not be possible to conduct full-fledged reliability programs conducted prior to the first launchings. This will be accomplished, however, as part of the man-rating programs, which will be carried out by the time manned flights are scheduled. We have also planned the manufacturing of whole nonflying stages for ground testing just prior to the manufacturing of the first stage ready for flight. These stages are:

Static test stages—sometimes called battleship stages—for the development of the overall propulsion system. A considerable number of hot firings of these are being conducted.

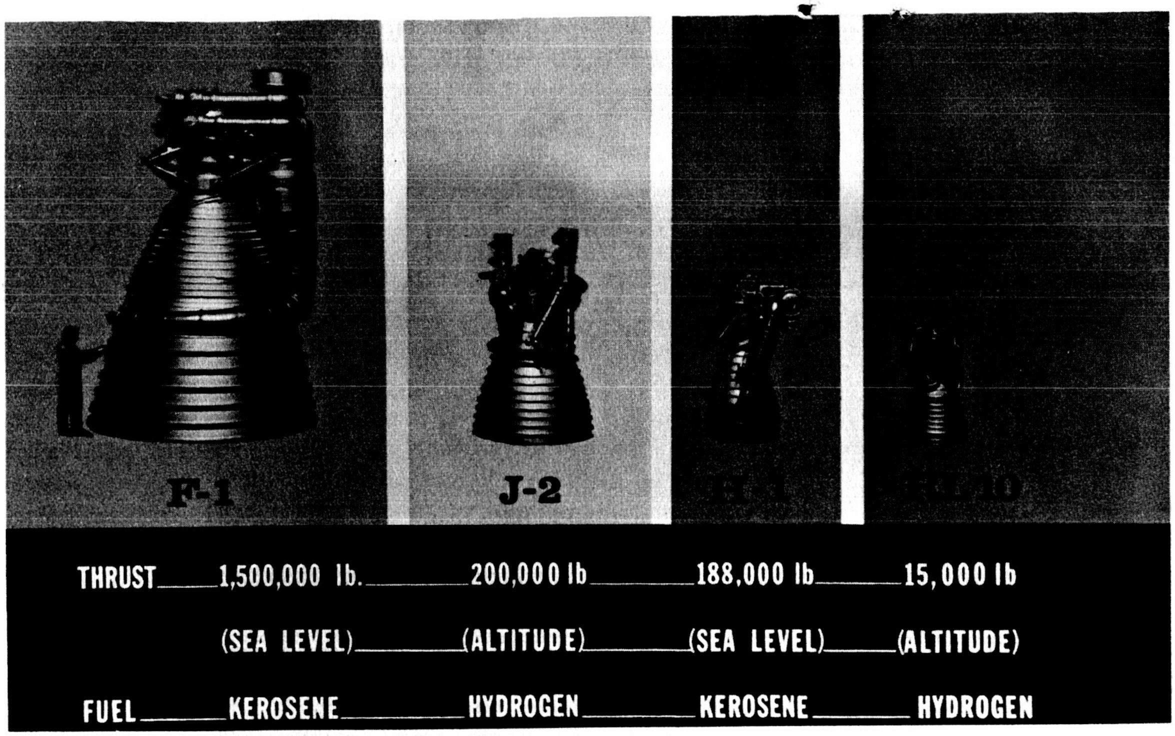

FIGURE 4.—Engines for space flight.

Structural test stages—for complete testing of the overall structure to establish safety margins and to obtain the lowest possible structural weights.

Dynamic test stages—for checking such matters as dynamic behavior, bending modes, and natural frequencies of the total configuration.

Facility stages—for the checkout of launch sites—requiring the use of the whole launch vehicle with its stages as close as possible to the final configuration with respect to such things as fueling systems, compatibility with launch tables and their holddown devices, and the vehicle's compatibility with swing arms, umbilical towers, and their equipment.

All systems stages—complete stages with all the features of a final flight stage—used for extensive static testing and a shakedown of all systems and subsystems and sometimes combined with the static propulsion test vehicle.

Many test activities with these nonflight articles must be done concurrently if a reasonable time schedule is to be met. Results and experience gained from the testing of one stage will be applied as far as feasible across the board.

Careful systems engineering is needed to assure that components of large systems for missions like Apollo, which are delivered from all over the country, are extremely well coordinated not only as to their proper delivery dates but especially as to such matters as their technical compatibility with each other and with the necessary ground support equipment and the launching site. We came to the conclusion that systems like the Saturn V, even in the early development stage, can no longer be checked by hand—that is, by the methods usually applied until now. Therefore, we had to develop an entirely automatic checkout system. The design and development of such a system is one of the systems engineering tasks of the first order. This system has to be applied while work is still in progress at the prime contractors' plants to match the final automatic checkout at the launching site.

We switched over to an "all-up" concept for the Saturn IB and Saturn V, in which all stages will be live at the first firing, in contrast to the concept we applied in the development program of the Saturn I launch vehicle, where we tried out first the first stage and later both stages. This causes little trouble in the Saturn IB, because the first stage is already proven in

the Saturn I program. It is, however, quite a challenge for the Saturn V program. Again, the third stages will have been tested on the Saturn IB, so we have only two new stages. The reason we changed to this concept is that we are trying to come to a final man-rated configuration as fast as possible. The earlier in the program we find shortcomings, the better.

Figure 5 shows a very crude line-up of the launching schedule. On Saturn I we have planned 10 launchings, of which we accomplished 5, all successful. The next firing is in the immediate future. It carries an Apollo spacecraft in its outside configuration. Numbers 8, 9, and 10 will take payloads into earth orbits for detection of micrometeoroids.

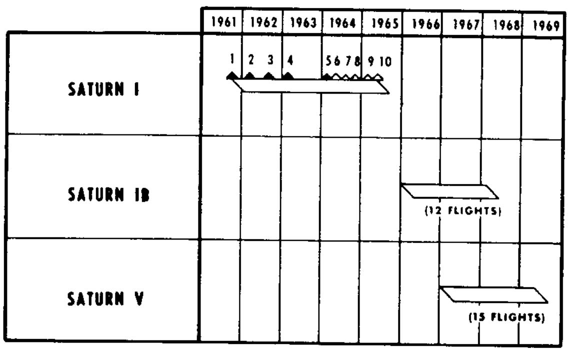

FIGURE 5.—Summary flight schedule for Saturn vehicles.

The first Saturn IB flight is scheduled for approximately early 1966. From flight 3 on, the launch vehicle will have a configuration allowing for manned flight.

The first Saturn V flight is scheduled for early 1967, approximately. We try, also, to have the capability for a manned flight beginning with the third vehicle.

For future large-launch vehicles, we should first exploit to the maximum extent what we have and build up from that platform. The Saturn IB lends itself extremely well to carrying a third stage. If we consider, for instance, the Centaur as such a third stage, we could take 35,000 pounds of payload into an earth orbit, and inject 13,000 pounds on a lunar mission or 7,000 to 8,000 pounds on a planetary mission. There are other third-stage possibilities. Refinement of the present two Saturn IB stages could increase these payloads by approximately 20 percent Similar refinements could be applied to the Saturn V stages, which would improve its performance by approximately 30 percent. Refinements in the area of weight savings and higher engine performance, which is in good reach, will play the largest part in these increases.

A future step will be the application of advanced propulsion systems. Some of these are merely in an exploratory paper stage; others are in research; and, again, others are already under development.

N64-30334

THE NATION'S FIRST SPACE PORT

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The Nation's first space port is now under construction at the John F. Kennedy Space Center, NASA. Our chairman, Mr. Holmes, had much to do with this undertaking during his tour in NASA, and we are happy to acknowledge his truly fine support. This paper covers some of the unusual developments in the facilities and equipment areas as well as our management plans and some future considerations for which provision has been made in our planning and designs.

To establish a frame of reference, it is necessary to go back to 1961, when NASA and the Department of Defense undertook a study to select a suitable location for the space port. Major General Leighton Davis represented the Department of Defense, and I represented NASA. We surveyed eight possible sites, including Hawaii, Christmas Island, locations in Texas and Georgia (including offshore islands), and the Cape Kennedy area.

An island base would offer distinct advantages but would also create serious problems in construction and logistics. Cape Kennedy offered the completely instrumented Atlantic Missile Range, plus communities to house our people, and good transportation networks. Further, there was available an undeveloped tract of lowland and swamp on northern Merritt Island, contiguous to the Cape, which would provide adequate room for building as well as the necessary buffer zones between the operational areas and the populated Florida mainland.

General Davis and I, therefore, recommended acquisition of the Merritt Island site of approximately 88,000 acres. NASA and the Department of Defense accepted the recommendation. In 1962 the Congress authorized NASA to acquire the property and has thus far authorized $74 million, of which we have committed $63 million to date.

The Merritt Island location lies between the Cape

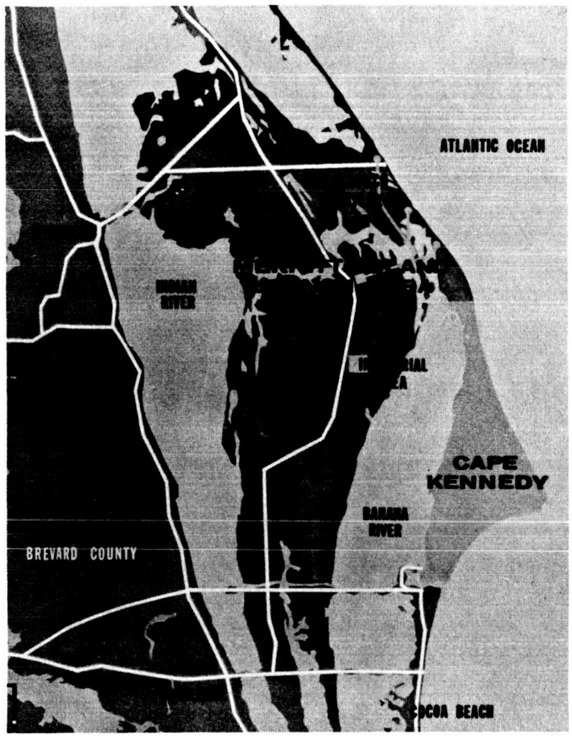

FIGURE 1.—Merritt Island location.

and the mainland (fig. 1). We are building causeways to provide direct access from U.S. Highway 1 to the NASA complex and the Cape. These arteries will be open to official traffic September 1 this year. We anticipate that they will become the principal means of access both to the Kennedy Space Center and to the Atlantic Missile Range.

About 42 percent of the total area west of Highway A-1-A, which bisects Merritt Island, has been placed under control of the U.S. Bureau of Sports Fisheries

and Wildlife for land management. This is subject to recall by NASA in the event of future need. Sportsmen will be interested in the fact that the Bureau has posted much of the tract as a wildlife refuge for the seasonal concentrations of waterfowl. We have also outleased some producing citrus groves, which will continue to play a part in the local economy.

Having received authorization to acquire the land, and more than 92 miles of shoreline on the Banana and Indian Rivers and the Atlantic Ocean, we set to work on the master plan for site development. From this we derived the funding requirements reflected in the Space Authorization Acts of fiscal years 1963, 1964, and 1965. As the following tabulation indicates, we have reached the investment peak; and the demands on construction funds will taper off quickly in the next and subsequent years until we are required to accommodate vehicles much larger than Saturn V.

Fiscal year	Land acquisition	Construction
1962	$57,750,000	
1963	$27,750,000	$261,466,000
1964		$274,491,000
1965		$89,520,000 (requested)

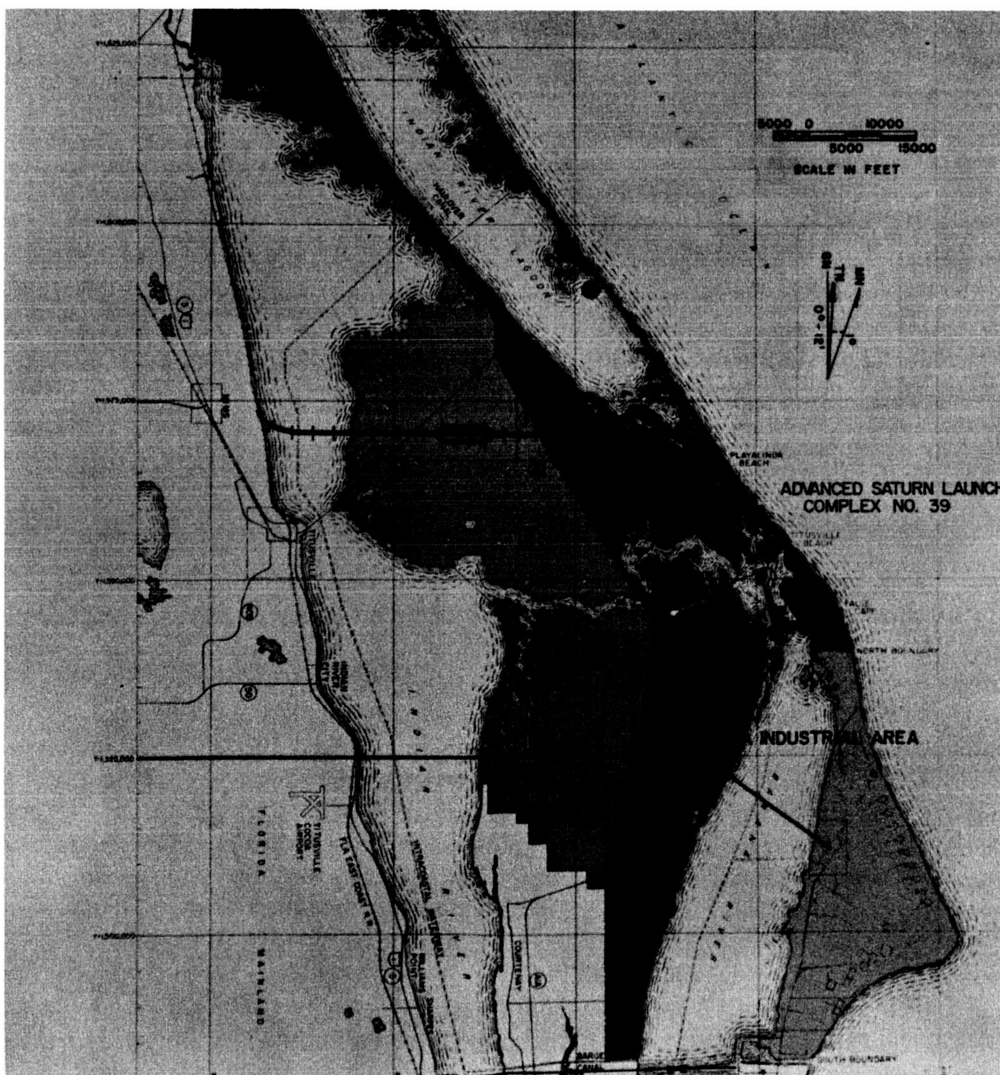

FIGURE 2.—Merritt Island industrial and launch areas.

Our planning focused on two major areas. One, in the southern portion of the site, is an industrial area directly west of Cape Kennedy across the Banana River (fig. 2). More than 50 structures are under construction. All the utilities and services expected of a municipality will be provided, such as a post office, fire and police stations, rail yard, heliport, and roads, and a communications center and dispensary which are already open and in business.

The foundation of the Kennedy Space Center Headquarters is being prepared (fig. 3). This will serve as the administrative center for the entire Merritt Island launch area. We expect to vacate our cramped quarters on Cape Kennedy next Spring and transfer into the new structure.

Another large structure site in the industrial area will house the field office of the Manned Spacecraft Center (fig. 4). This is the Operations and Checkout Building, in which Gemini and Apollo spacecraft will be assembled and inspected prior to mating with their launch vehicles. Here, too, quarters will be provided for the astronauts who will live at the launch site for several weeks prior to flight.

The first of the mission facilities will be ready for occupancy in June. This will be comprised of a group of buildings identified as the Fluid Test Complex (fig. 5), where MSC will first check out Gemini capsules. These structures are located along the eastern edge of the industrial area and will be used for preflight tests

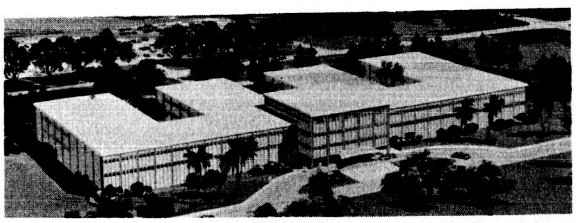

FIGURE 3.—Kennedy Space Center Headquarters.

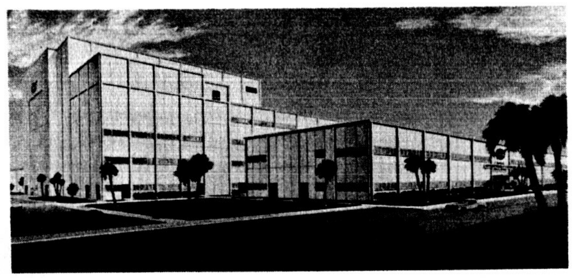

FIGURE 4.—Operations and Checkout Building.

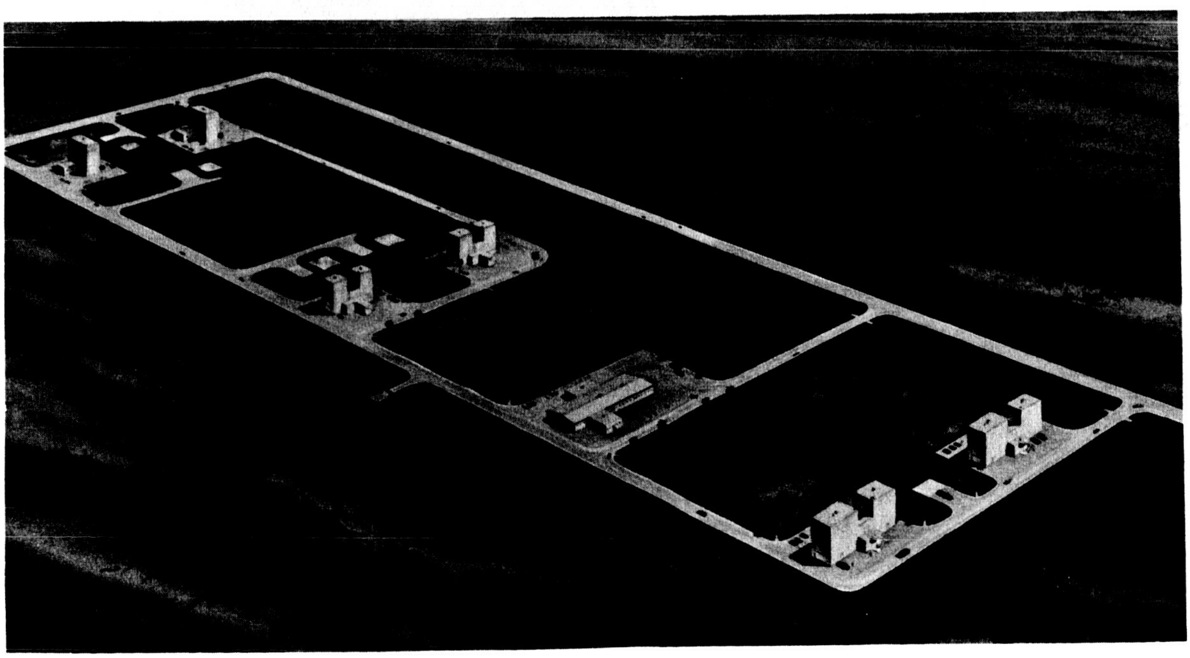

FIGURE 5.—Fluid Test Complex

of life-support equipment and propulsion systems of Gemini and, later, the Apollo spacecraft.

The Central Instrumentation Facility will be located next to the Kennedy Space Center Headquarters. It will function as the primary distribution point for data received from NASA and Atlantic Missile Range instrumentation during checkout and launch of heavy space vehicles from Complex 39.

Mechanical engineering buildings, laboratories, and warehouses round out the industrial area complex.

Seven miles north of the industrial area, construction is in progress on Launch Complex 39 (fig. 6). It involves an investment of nearly $450 million, which is without precedent in the category of U.S. launch facilities. But, then, so is the complex itself. The real distinction of Complex 39 is the operational concept which shaped its design.

Conventionally, the stages of large space vehicles have been separately transported to the launch pads and assembled, using heavy service structures for this purpose. This means that the vehicle is fully exposed to weather and the corrosive effects of the beach atmosphere. This is true of the present Saturn I facilities, such as Complex 37, pictured in figure 7. In effect, this constrains the launch preparations to a fixed facility and has the major disadvantage of concentrating prelaunch assembly and checkout operations right on the pad. This not only denies any flexibility but ties up the entire launch complex for months in the case of man-rated vehicles. It also rules out any possibility of rapid and successive launches which should be anticipated in lunar missions or the resupply of orbiting space platforms.

Complex 39 was designed, therefore, to eliminate these imposed conditions. For the first time, we will have a mobile facility. With the advent of Saturn V, we can assemble and prepare the entire machine for flight in a controlled environment, then transport it to the pad, fuel, and launch it in minimum time.

FIGURE 6.—Launch Complex 39.

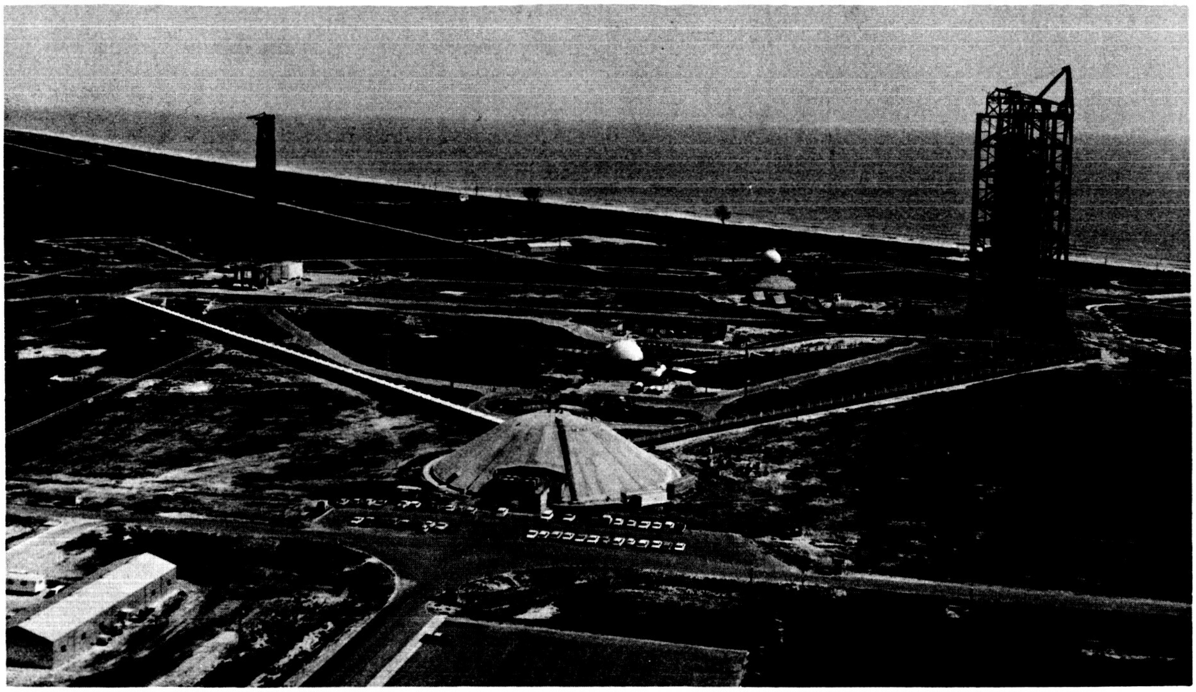

FIGURE 7.—Complex 37.

The assembly and checkout functions will be accomplished in a hangar, instead of on an exposed service structure. It will be possible to move the entire vehicle, not just pieces of one, out of the way of such hazards as storms. Since the pad is not tied up, except for a relatively short period during the actual launch, we can schedule successive launches from the same facility. We will carry the service tower with the launch vehicle and transfer them as a package from hangar to pad, or vice versa if necessary.

As is true in other facets of the Saturn program—such as manufacturing, testing, human engineering, and launch operations—the construction phase is also a first. It involves the construction of some very large structures and the fabrication and assembly, on site, of a crawler-transporter capable of moving the complete Saturn/Apollo configuration between assembly building and launch pad.

The Vertical Assembly Building (VAB), in which the Saturn V/Apollo will be assembled and checked out, will be a smooth steel box of rather large proportions—710 feet long, 518 feet wide, and 552 feet high, which is a little higher than Florida's palm trees. Much of the structural steel is already in place (fig. 8 and 9). The challenge which this structure posed to the architects and engineers of the design team has been very well stated by Max Urbahn, who headed this group:

> The VAB is not so much a building to house a moon vehicle as a machine to build a moon craft. The Launch Control Center that monitors and tests every component that goes into an Apollo vehicle is not so much a building as an almost living brain.

In the high bay area of the VAB (fig. 10), beneath a ceiling 50 stories high, there will be multilevel

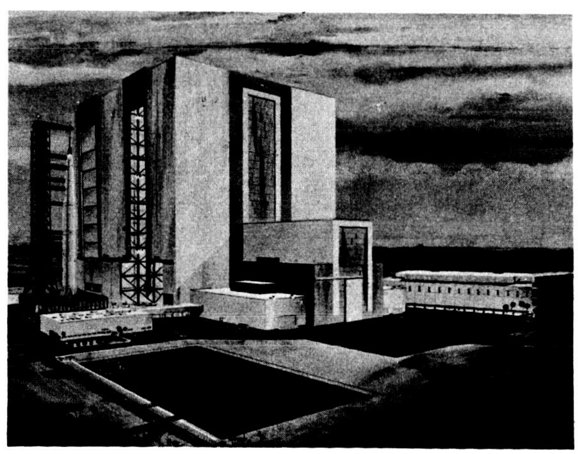

FIGURE 8.—Vertical Assembly Building.

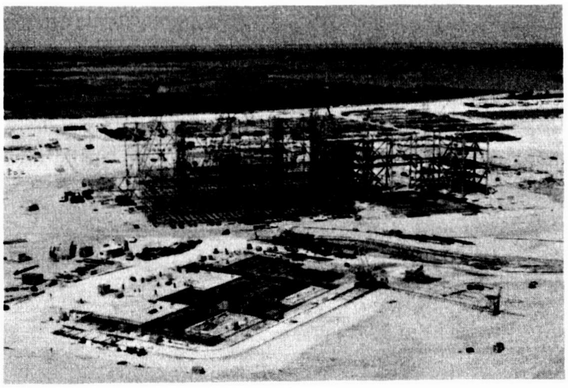

FIGURE 9.—Construction of Vertical Assembly Building showing structural steel in place.

platforms, each as large as a three-story house, suspended from the walls. These structures will enclose the Saturn V/Apollo and provide access to the entire vehicle at any height. The VAB will accommodate four complete vehicles simultaneously and thus facilitate a high-launch rate. Only two of the four bays will be equipped initially.

The low bay area, although less imposing, is by any other measure a very large structure (fig. 11). Here the upper stages of the Saturn V/Apollo will be received and inspected before the 175-ton transfer aisle crane picks them up and moves them into the high bay for sequential assembly atop the booster. The entire building will be ready by early 1966.

The Launch Control Center (fig. 12) is a semidetached wing of the VAB that will house all systems required in checkout and launch operations. We plan to employ digital data transmission techniques of data and quality. This Center will be located 3 miles from the launch pads; thus, there is no need for the conventional, bomb shelter-type construction. Instead, the launch team will enjoy a picture window view of pad work and the actual launching.

The Launch Control Center will be connected with the vehicle through the launch umbilical tower (fig. 13) on which it will be assembled within the VAB. The mobile LUT, as we call it, resembles a conventional launch pad; but it is much larger and, more significantly, it is movable. Its mobility is the key to the operation of Complex 39. The LUT has a supporting platform one-half acre in size and 25 feet thick. Inside are 30 compartments on two levels, where much of the electrical and pneumatic equipment normally housed under the launch pad can be

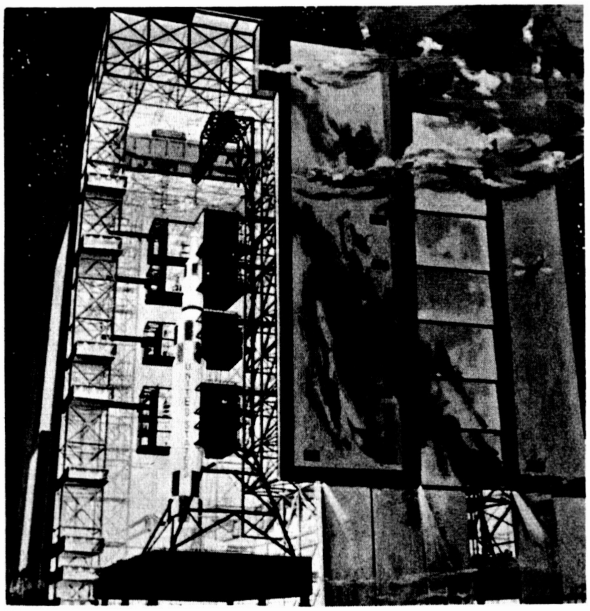

FIGURE 10.—High bay area of Vertical Assembly Building.

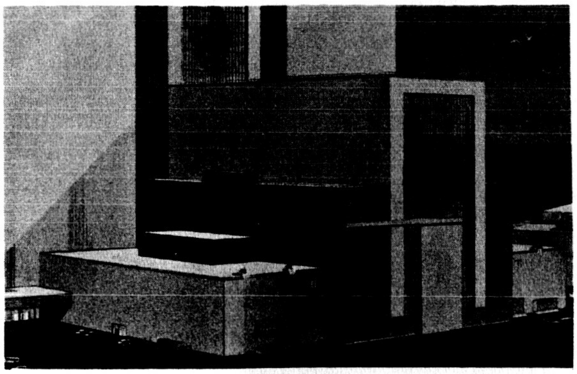

FIGURE 11.—Low bay area of Vertical Assembly Building.

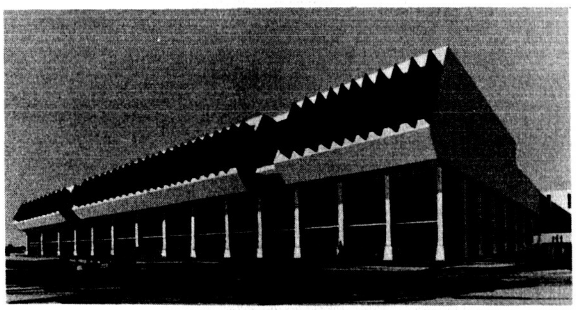

FIGURE 12.—The Launch Control Center, a wing of Vertical Assembly Building.

placed. Through the LUT's systems, the launch crew can supply pneumatic, electrical, and propellant feeds to the vehicle at various levels.

When the vehicle is ready for transfer to the pad, the crawler-transporter (fig. 14) will come into use. This machine is really an oversized version of the heavy crawlers developed by the earth-moving industry and often employed in strip mining. Its proportions are such that it could not be transported from point of manufacture to Merritt Island, so it is being brought to us in manageable pieces and assembled on site. It will weigh 5.5 million pounds when completed and can transport up to 12 million pounds.

Several days before launch the crawler will pick up the LUT and the space vehicle (fig. 15) and move them to the pad. It will then reverse its course toward the VAB, traversing a specially prepared roadway some 8 feet thick, and transport the arming

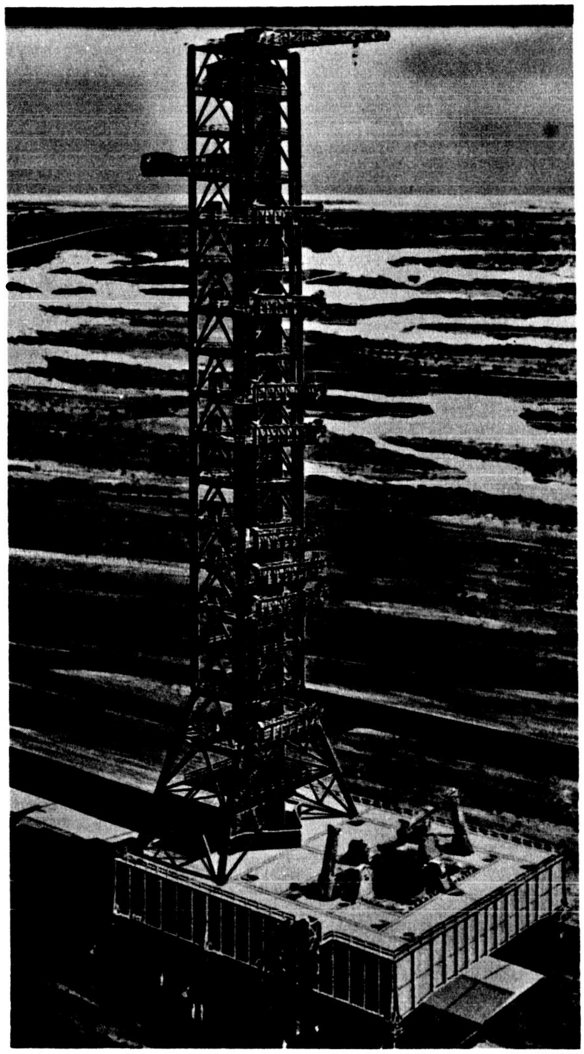

FIGURE 13.—Launch umbilical tower (LUT).

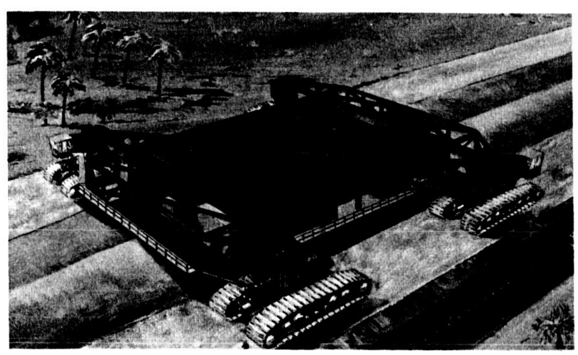

FIGURE 14.—The crawler-transporter.

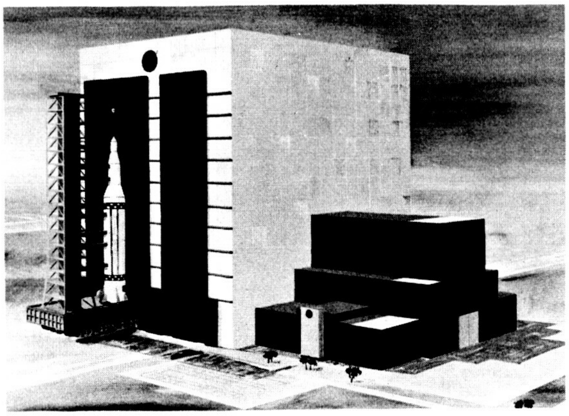

FIGURE 15.—Transfer of launch umbilical tower and vehicle by the crawler from the Vertical Assembly Building to the launch pad.

tower (fig. 16) to the pad. This tower will be 340 feet tall; it will provide 360-degree access during the installation of sensitive or residual ordnance at stage junctions, and during fueling of the spacecraft. The arming tower will be withdrawn 7 hours prior to launch.

As mentioned in connection with the crawler-transporter, much of the ground support equipment is being assembled at the space port. We have reached the phase in manned spaceflight where the facilities and equipment necessary for launch operations are so large as to make it impractical to assemble them elsewhere. Thus, the first of the LUT's is also arriving in piecemeal fashion and is now in process of erection where the crawler is under assembly.

The crawlerway is being graded in preparation for paving from the VAB area to the pads near the ocean beach. Good progress is being made in the entire construction project. The Army Engineers are supervising the facilities construction for NASA.

Similarly, in the less technical aspects of the Kennedy Space Center activities, we have placed increasing reliance on industry. In the past, the Air Force provided this kind of support through a base contractor at Cape Kennedy. The Merritt Island launch area is, however, an exclusive NASA responsibility. So we decided to divide the support functions into four areas: administration and maintenance, instrumentation, base operations, and launch support operations.

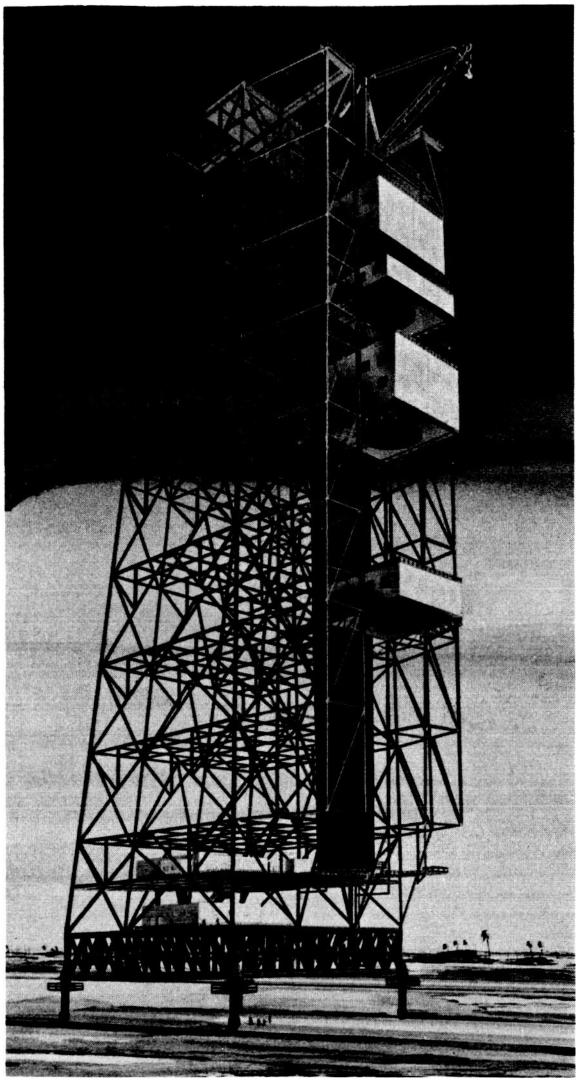

FIGURE 16.—Arming tower.

We then selected firms specialized in the first three of these fields of activity and negotiated contracts with them with a basic value of from $1 million to $7 million for fiscal year 1965. The launch support operations contract has not yet been concluded. Each of the support contracts contains an incentive award provision, plus an option to extend it for 2 additional years, or a total of 3 years; in this way we hope to retain and preserve the experience gained by the contractor.

To put it briefly, the Merritt Island launch area can accommodate the next class of space boosters beyond

Saturn V, perhaps of 25 to 40 million pounds thrust. We have conducted studies of noise levels, explosive safety distance requirements, and other factors; the results indicate quite clearly that is is feasible to launch such vehicles from the space port. We have reserved a fairly large area north of Complex 39 for more advanced facilities whenever the space program may require them.

Looking farther down the road, and applying my personal judgment as to the logical trends, the sequentially staged vehicles may, with Saturn V, reach their limits of height and slenderness ratio. Anything beyond the Saturn V would present enormous problems of structural integrity. So I consider it likely that the 25 to 40-million-pound-thrust boosters may be much shorter and stubbier, much larger in diameter, but designed for launching from the new space port. When the future space program demands even more powerful boosters than those of the 40-million-pound class, I believe we may have to go to sea to assemble and launch them from pads similar to the Texas tower-type oil rigs.

NASA is investigating methods of transportation, or resupply, between points on Earth and very large spacecraft or space platforms. One concept would employ sled-boosted, two-stage vehicles. The *first stage* would be reusable, and its function would be to carry the upper stage and payload beyond the atmosphere. Then its astronaut pilot would fly that first stage back to a jet airfield. The *second stage,* also reusable, would transport passengers or freight to the space station and be capable of reentry and operation within the atmosphere to land at its operational base. This concept seems to be the most promising area for investigation. The big boosters, in my judgment, would be useful only for launching very heavy mass into space.

In any event, the learning curve is rising rapidly. I firmly believe that this nation can and will do anything which the people determine as the national policy for the future exploration of the universe.

N64-30335

MAN'S FLIGHT IN SPACE

George E. Mueller
Associate Administrator for Manned Space Flight
National Aeronautics and Space Administration

It is a pleasure to participate in this *Man in Space* session of the Fourth National Conference on the Peaceful Uses of Space. Dr. Gilruth has given an excellent review of the origins of manned space flight, the Mercury program, and the beginning of the flight phase of the Gemini program earlier this month.

The previous papers of this session have focused on the details of the Apollo program. Dr. Shea reported on the Apollo spacecraft, Dr. Rees discussed the Saturn launch vehicles, and Dr. Debus told of the plans and progress in the construction of the space port at the Kennedy Space Center.

This paper summarizes the progress to date in the Apollo effort and reviews some overall Apollo considerations and the benefits that the country will gain from Apollo. Figures 1 to 4—photographs and artists' drawings of facilities at the Marshall Space Flight Center, Kennedy Space Center, and Mississippi Test Operations Site—are a progress report on filling the pipeline for the nationwide Apollo effort.

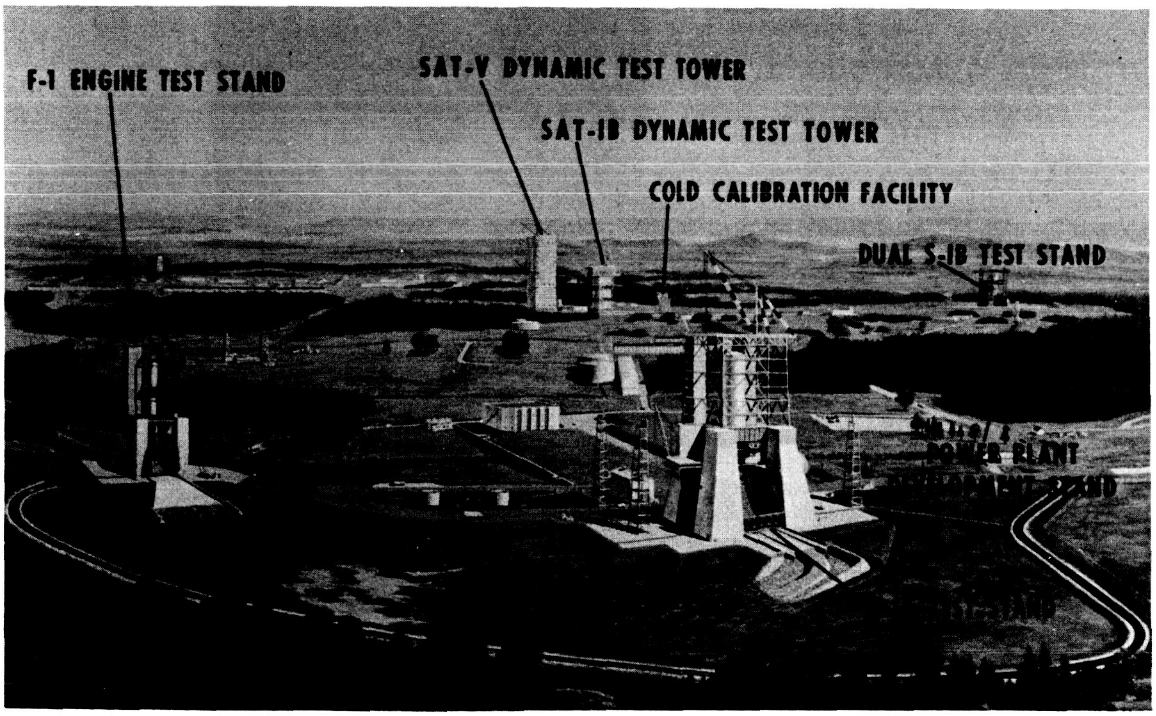

Figure 1.—Test area at Marshall Space Flight Center.

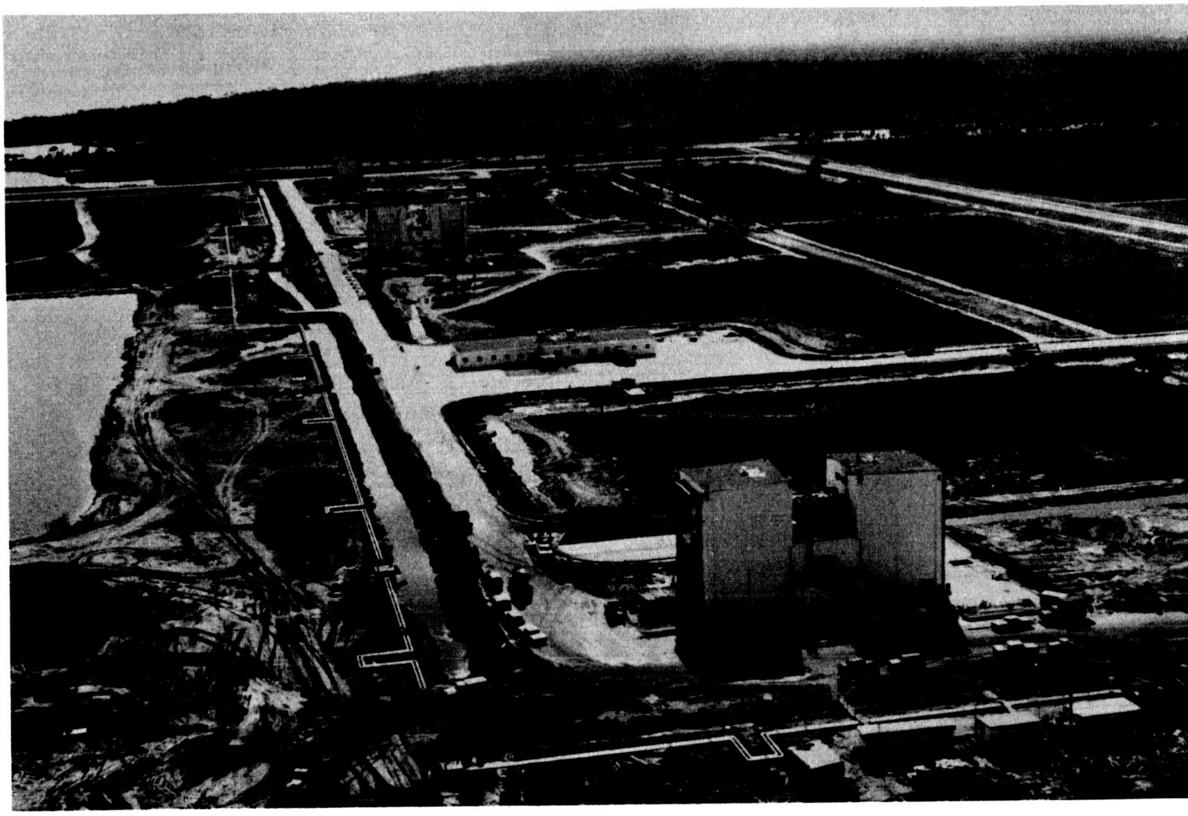

FIGURE 2.—Apollo spacecraft Fluid Test Complex at Kennedy Space Center (January 1964).

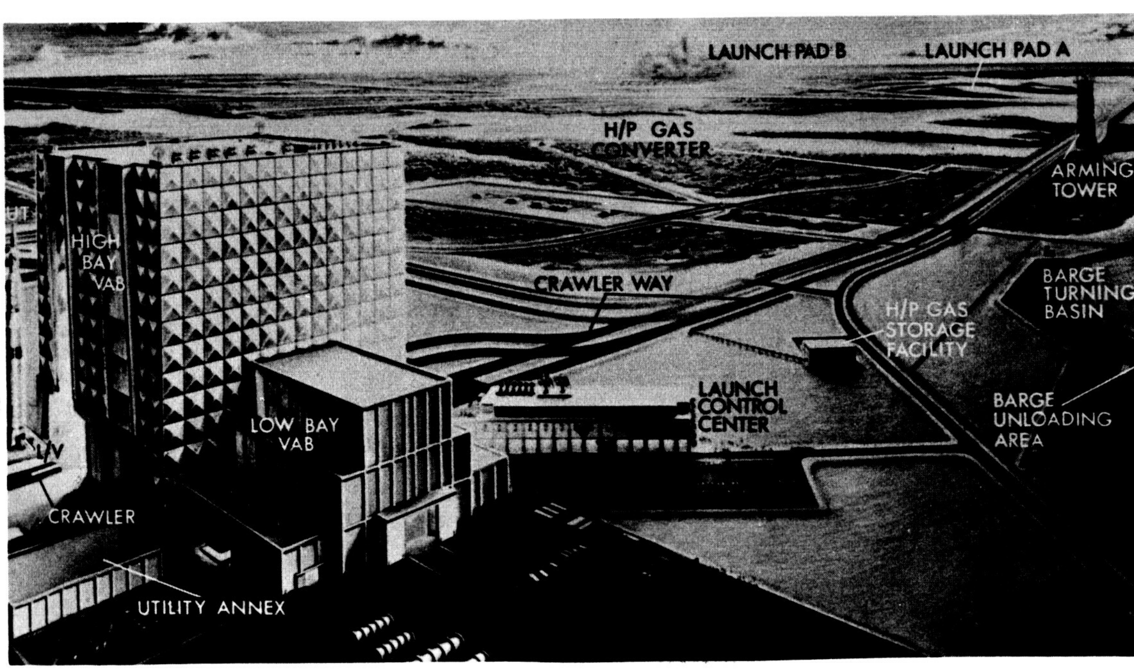

FIGURE 3.—Artist's sketch of vertical assembly building area at Kennedy Space Center.

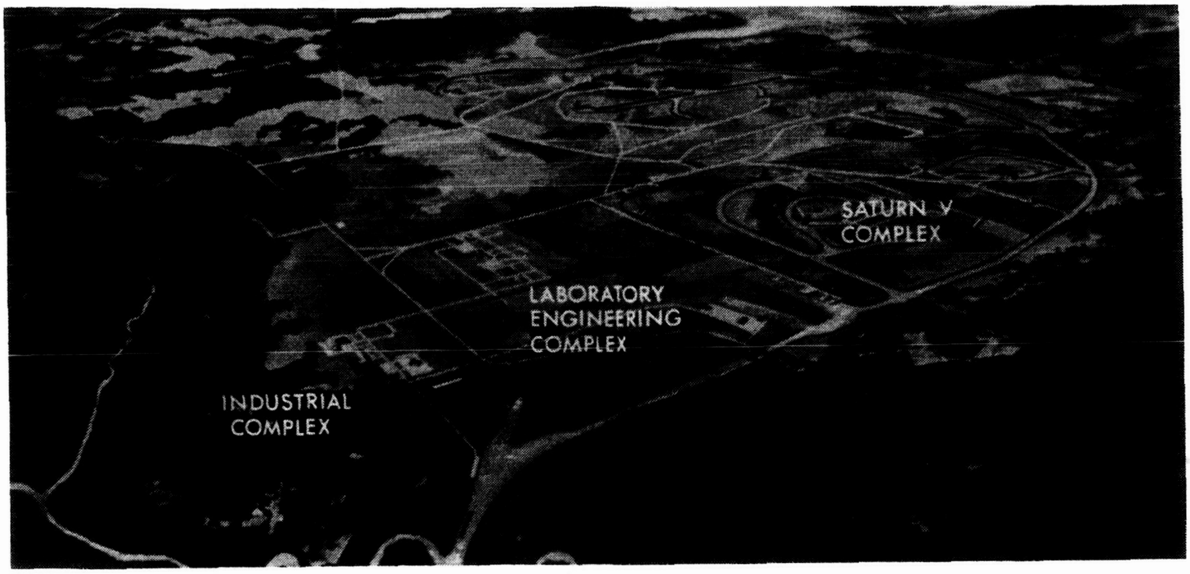

FIGURE 4.—Mississippi Test Operations Site plan. To be completed in 1966.

Much progress has been made in the Apollo program (fig. 5) which can be truly said to have been started in 1958, the year that Congress passed the Space Act. It was in that year that work began on the Saturn I launch vehicle, the F–1 engine, and the Centaur program, in which this country pioneered in the use of liquid hydrogen as a rocket fuel.

It was because of the progress of these efforts, as well as that in the Mercury program, that it was possible to broaden and accelerate our country's efforts in space (fig. 6) 3 years ago this spring, and that President Kennedy could set as a national goal the beginning of manned lunar exploration in this decade.

In recent months, we have carried out a series of reviews of the progress of development of the systems and subsystems within the overall Apollo system. We could find no technological problems of such a major nature that they would interfere with the accomplishment of the program on schedule. Indeed, we could not find one that is not yielding to hard work.

It appears that the most challenging technical task before us is the integration of all of the systems and subsystems—in making them all work properly together. The flight schedule, therefore, is laid out in a way calculated to permit carrying out this integration as early as possible.

We have also recently reviewed a number of matters related to the overall pace of Apollo. We have compared the Apollo pace with that of other major research and development programs carried out by the United States in the past. We have examined the impact on total cost of possible changes in the Apollo schedule; and we have studied the relationship between the pace and the conditions in the space environment.

The overall time phasing, we found, is actually quite conservative. The Apollo spacecraft is being developed on a schedule 4 years longer than was needed for the Mercury spacecraft, and 2 years longer than was needed to produce the B-58 bomber. The Saturn IB and Saturn V launch vehicles are being developed on a schedule 2 years longer than that of the Atlas missile, and 1 year longer than was required for the Titan. The total duration scheduled for the Apollo program is longer than that of any previous United States research and development effort.

The Apollo job, of course, is a big one, and we will need all of the time allotted. The number of parts, components, and subsystems is greater, and they must function for longer periods of time. But the problems lend themselves to orderly solutions; no new inventions or breakthroughs are required. We have generated a high degree of momentum, and the work is going forward effectively and efficiently.

Our recent reviews also examined how the pace affects total cost. In particular, we looked into the

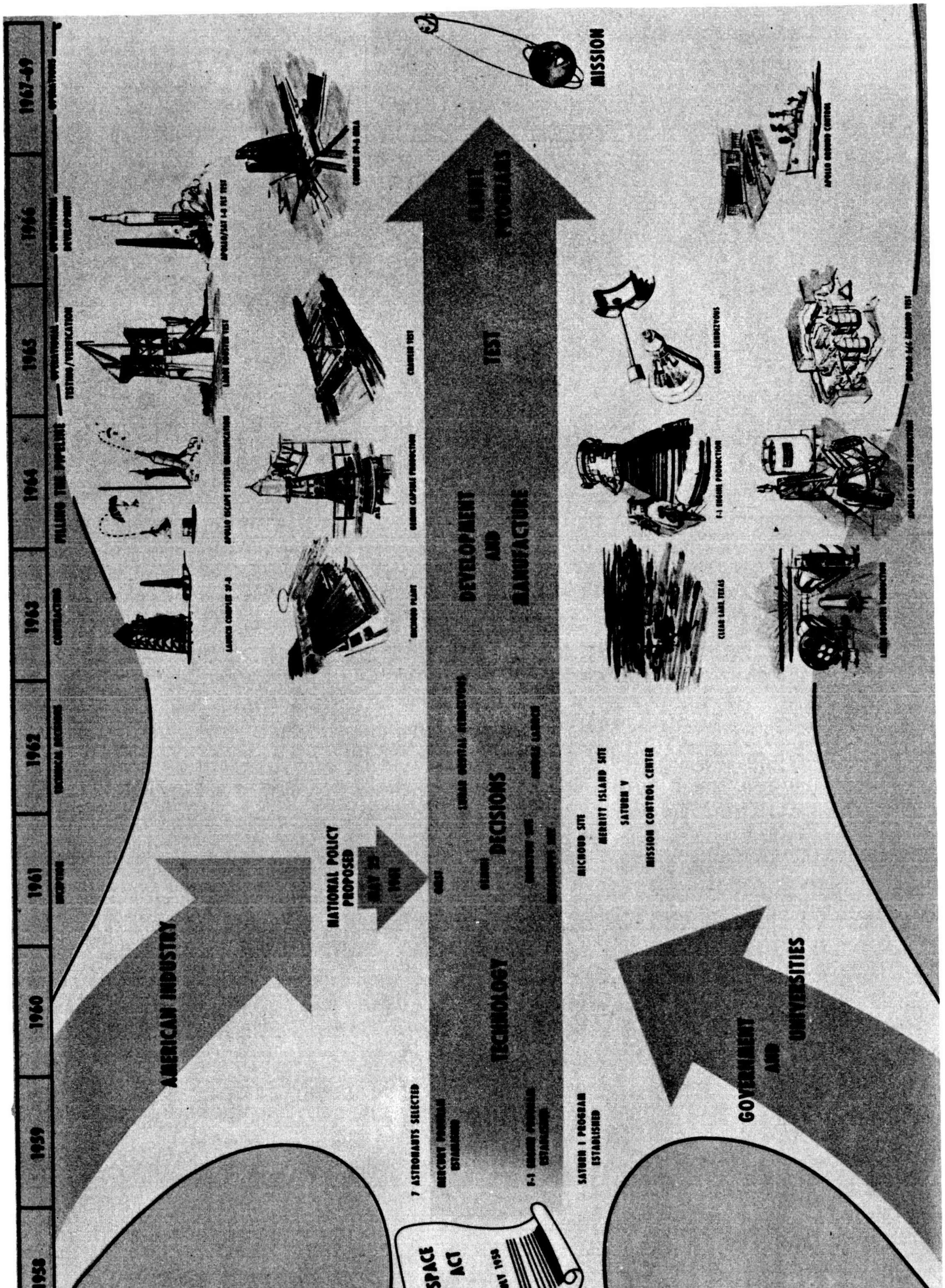

FIGURE 5.—Evolution of the Apollo program.

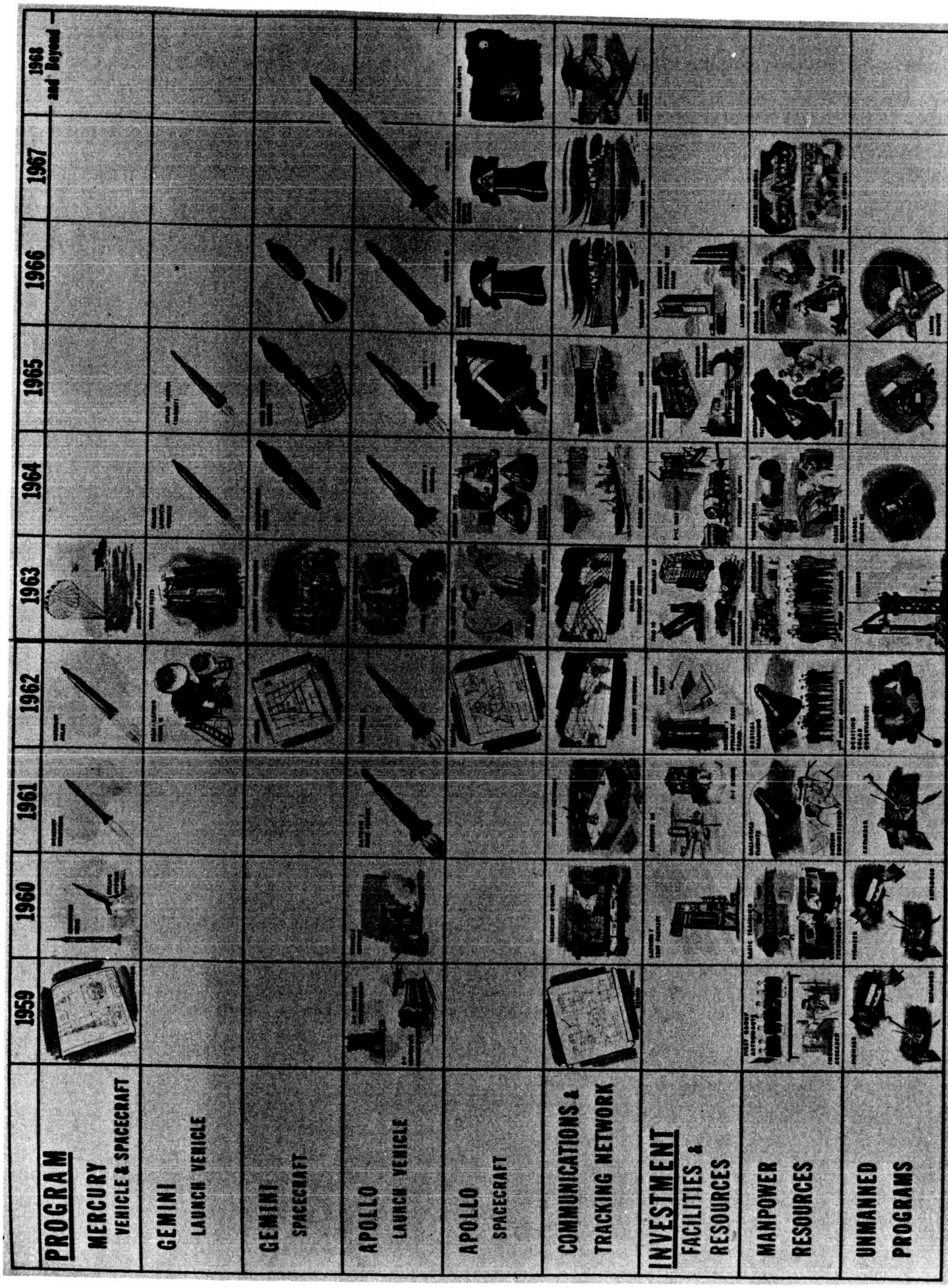

FIGURE 6.—Elements of manned space flight program.

effect on total cost that would be caused by a slowing of the effort and a stretchout of the completion date to the 1970's. This was done in great detail. We studied, subsystem by subsystem, the resource requirements associated with the present schedules. To do this, we analyzed thoroughly the requirements in man-hours for the work to be done in engineering and manufacturing. Then we added the costs of overhead and the operating burden needed to support the work, not only within the NASA organization but in those of the contractors and subcontractors involved.

We found upon completion of the calculations that if the remaining 6 years of work were stretched out over 12 years the total cost of the presently approved manned space flight program would increase by about 30 percent, or about $6 billion. The economic considerations, therefore, support the maintenance of the present schedule. It is $6 billion cheaper to continue on the course we are now following than to set out on a new course at this late date.

Still another area of review of the Apollo pace was the effect of conditions in the space environment. We looked into the matter of meteoroids in space. We examined the effect of radiation in space, and we studied the question of conditions on the Moon's surface.

With respect to meteoroids, present knowledge mainly originates in the data from the Explorer XVI satellite launched by NASA on December 16, 1962, and visual and radar ground observations of meteor arrivals in the upper atmosphere. The results from Explorer XVI indicate that the rate of puncture of the Apollo spacecraft skin by meteoroids would be considerably less than had been anticipated earlier on the basis of indirect calculations from ground observations.

Further meteoroid information will be obtained on the 8th, 9th, and 10th flights of the Saturn I, which we anticipate will provide confirmation of the Apollo spacecraft design criteria. As additional data are obtained, we will continue to review this matter very carefully. However, it is not expected that meteoroids will constitute a major problem in the planning or scheduling of the first manned lunar exploration.

We reviewed the potential radiation hazard from cosmic rays originating elsewhere in the galaxy, charged particles trapped in the Van Allen radiation belts, and high-energy particles ejected during solar flares. The danger from the cosmic rays and the Van Allen belts during typical Apollo missions is negligible. Solar-flare protons are largely diverted by the Earth's magnetic field and, therefore, do not present a hazard in the portion of the Apollo trajectory below the belts. Therefore, the only portion of the mission about which there is any need for detailed solar-flare calculations is that part in which the spacecraft is in flight beyond the Van Allen belts.

The permissible safe limits for radiation are based on a 1962 report of a working group set up by the Man in Space Committee of the Space Science Board of the National Academy of Sciences. The most important limit recommended by this group is that of 100 rads as the maximum permissible dose received by the blood-forming organs.

In our reviews, we looked into the dose that would have been received within the command module by astronauts on a normal Apollo mission if one had taken place during a large solar flare. We found that in the largest recorded flare, that of July 1959, the dose to the blood-forming organs would have been 15 rads. Thus, the worst flare known would have given the astronauts only 15 percent of the allowable safe dose.

Altogether, the evidence available indicates that radiation does not present a hazard that would prevent manned lunar exploration in this decade. In fact, we have encountered no serious evidence that would indicate that radiation would be a factor in scheduling the first lunar mission.

The third environmental matter reviewed was the selection of the lunar-landing site. Present information on the surface of the Moon is based on observations from Earth, analysis of radar echoes, analysis of the rate of arrival of meteors, and analogies to Earth. Study of this information indicates that it will be possible to find many suitable sites for landings on the Moon. The landing gear of the lunar excursion module (LEM) is being designed to cope with a wide variety of possible surface conditions, and the LEM is capable of lateral flight so that a satisfactory landing site can be chosen by the astronauts.

We anticipate that further information regarding conditions on the Moon will be provided by the unmanned lunar missions—Ranger, Surveyor, and Lunar Orbiter—and that this information will confirm the design criteria being established for the LEM. Apollo plans are proceeding on the assumption that these programs will be capable of providing all the information needed for site selection.

Altogether, we found that the present Apollo schedule is soundly conceived, compatible with economy, and in phase with the scientific and technological progress that will be needed to cope with the space environment.

Some of the returns that the Nation obtains from the Apollo investment are so well understood that they need be merely mentioned in passing. It is clear, for example, that the demonstration of the ability to conduct manned exploration of the Moon (fig. 7) will greatly increase United States prestige and influence in an area in which another nation has held the lead. It is equally clear that the exploration of the Moon expands human knowledge to a very large degree. And it is clear that the conduct of a program of research and development on the scale of Apollo contributes significantly to general technological advance in the form of new materials, methods, and processes, and in the resulting stimulus to the Nation's economic growth.

Still another set of benefits from Apollo are the rapid advancement of United States capability in space and the ability to undertake whatever space activities the national interest may require. There are seven major elements in this capability—people, industrial base, ground facilities, launch vehicles, spacecraft, operational know-how, and the ability to manage research and development. Together, they add up to space power, which provides this Nation with freedom of action in this new medium.

First, and most important is people. We estimate that a quarter million people are now at work on manned space projects throughout the United States. Their numbers will increase to about 300,000 by next year, when the effort on the presently approved manned space flight program reaches its peak.

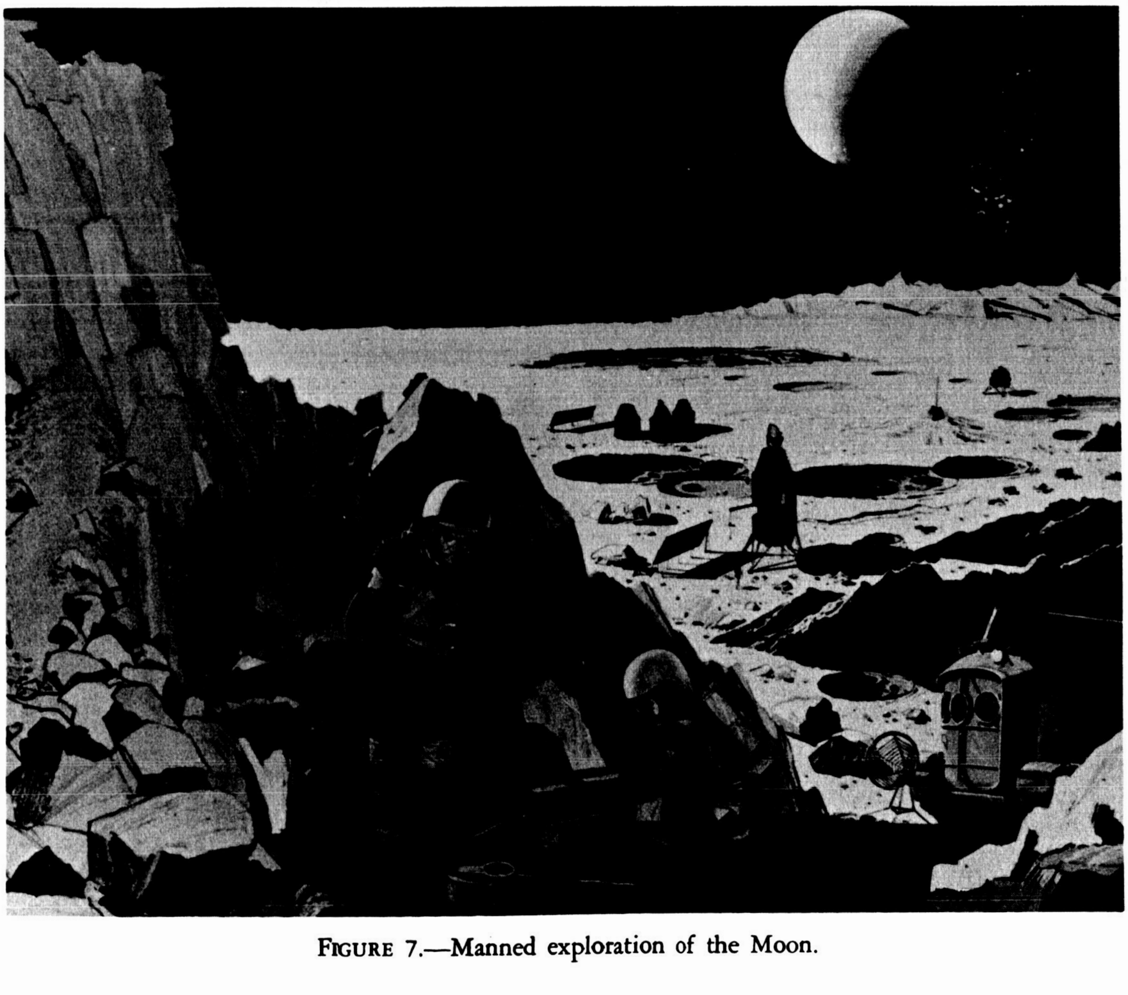

FIGURE 7.—Manned exploration of the Moon.

At this maximum level, the team will include about 45,000 scientists and engineers, about 2.8 percent of the total national employment of scientists and engineers. This number is substantial, of course, but it is clear that the requirements for manned space flight do not strain the national supply of highly qualified manpower. In fact, quite the opposite is the case. Industry has repeatedly informed us that it has available the people to undertake additional efforts beyond those contemplated in the present programs.

A second element of capability is the industrial team that has been assembled. Every region of the country is participating. In some areas, the work is focused in the NASA Centers and military installations; in others, prime contractors are prominent; in still others, subcontractors, supplier and vendors play the major role. The effort is truly national.

Third are the ground installations needed to operate in space. These include institutional, design and manufacturing, testing, launching, and operational facilities in many parts of the United States, and the network of tracking stations around the world.

Earlier in this session, Dr. Debus focused attention on the facilities of the Nation's space port at Merritt Island, Fla. An extremely important item is the launch vehicle. The Saturn vehicles (fig. 8) being developed in the Apollo program will make the United States second to none in this vital area.

Dr. Rees pointed out the capabilities that these vehicles and the facilities for their production will provide to the country upon completion of the present program.

Another element of capability is the Apollo spacecraft, described by Dr. Shea, in which three astronauts will be able to navigate and maneuver, make rendezvous with other spacecraft, and remain in orbit for extended periods of time. The two-man LEM, the first U.S. spacecraft designed wholly for operation beyond the Earth's atmosphere, will provide us with the ability to carry on a number of experiments in earth orbit for the first time. Figures 9 and 10 show manned orbiting laboratory (MOL) and ferry system concepts.

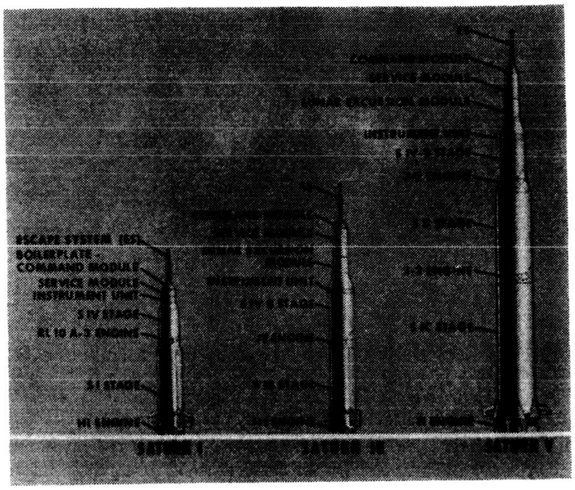

FIGURE 8.—Saturn vehicles for Apollo program.

An extremely important dividend from the Apollo investment is experience and know-how in operations. We are learning what must be done on the ground and in flight; in vehicle assembly and automatic checkout; in launching space vehicles on time; in tracking and telemetering and transmitting vast quantities of information; in calculating flight paths and midcourse maneuvers; in landing on another astronomical

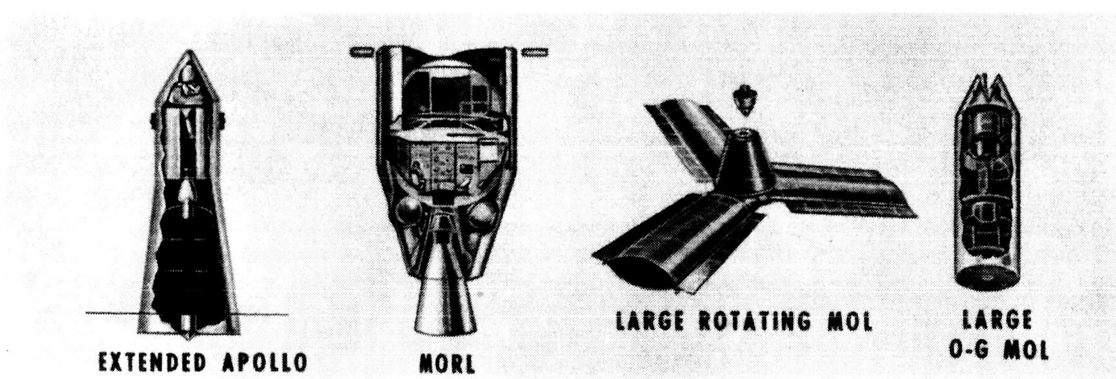

FIGURE 9.—Manned orbiting laboratory concepts.

FIGURE 10.—Ferry systems.

body and taking off without the assistance of a ground crew; in returning to the atmosphere at 7 miles per second; in controlling the flight path through the atmosphere; and in returning to Earth on land or water. We are learning how to conduct such a mission, involving two spacecraft, at a distance up to a quarter-million miles from the earth. Figure 11 is a typical Apollo mission profile for a lunar orbital rendezvous.

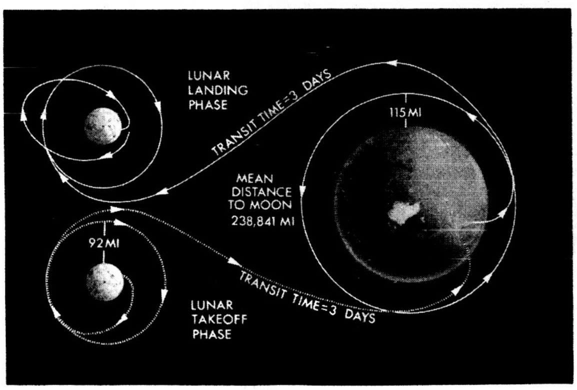

FIGURE 11.—Typical profile of lunar orbital rendezvous mode mission.

Finally, in Apollo we are taking a long stride forward in the creation of the ability to manage a very large research and development effort. From the Manhattan Project of World War II to the ballistic missile programs of the 1950's was one very large step. Now we have moved on to a program even more extensive in scope, managed at three locations under the overall direction of the Apollo Program Office in Washington.

In this development of national capability—people, industry, facilities, launch vehicles, spacecraft, operations, and management—NASA in the Apollo program is carrying forward the work begun a half century ago by its predecessor agency, the National Advisory Committee for Aeronautics (NACA).

Like NACA, the space agency is concentrating its efforts on research and development. The only significant difference is that NASA also conducts operations in space. Thus, we are developing the methods of operation in space as well as the needed technology.

Many of the most significant advances in military and civil aviation resulted from fundamentals of flight developed by NACA. Frequently, this work was carried out with the sole objective of solving basic problems of flight. It did not wait for any statement of a specific military or civilian requirement. The requirements developed naturally after it became known what capabilities it was possible to develop.

In 1943, Secretary of the Navy Frank Knox stated that the Navy's World War II fighter aircraft, the Corsair, Wildcat, and Hellcat, were possible only because they were based on such fundamentals developed by NACA as wing sections, cooling methods, and high-lift devices. "The great sea victories that have broken Japan's expanding grip in the Pacific," Secretary Knox said, "would not have been possible without the contributions of the NACA."

Last December, we saw the first major example of the application to military use of the manned space flight capability developed by NASA—the decision of the Department of Defense to use the Gemini hardware (fig. 12) and experience as the basis of its Manned Orbiting Laboratory program. The capability developed in Apollo will also be available if required to fill the needs of the Department of Defense. This national competence will serve the country long after the Apollo program has been completed.

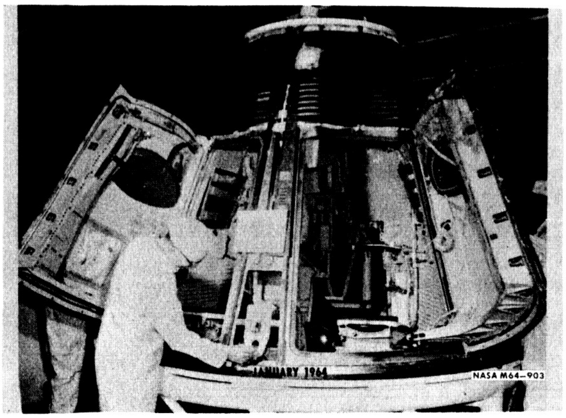

FIGURE 12.—Gemini spacecraft No. 2 in systems test.

In fact, fully 90 percent of the work now in progress in Apollo would be done to create space power even if there were no Moon and the program had an entirely different ultimate goal. In the Apollo program, the Moon is the focus of this great national effort to make the United States clearly first in space. It is a clear objective, toward which we find it possible to organize the work in an effective, efficient manner, at a carefully coordinated rate.

Apollo is an orderly program. Its momentum has been increasing steadily for almost 3 years. We will reach maximum effort next year. The funding proposals now before Congress will bring us halfway to the Moon.

With your support, we will arrive on schedule.

30336

THE FUTURE

(Dinner Meeting)

Chairman
JAMES M. GAVIN
Chairman of the Board
Arthur D. Little, Inc.

N64-30336

THE FUTURE OF SPACE

WERNHER VON BRAUN
Director
NASA George C. Marshall Space Flight Center

The subject of space is very dear to my heart. It is dear to my heart not solely because I am in the launch-vehicle business, and it serves my vested interest best to speak out as eloquently as I can in favor of it. The space program is also dear to my heart because I am an American citizen, and I truly believe that this program serves the best interests of the United States, both domestically and internationally.

Space is a popular subject. It is popular not only to those of us directly involved in the various phases of the program, but it is a popular subject with the man on the street. I do not believe there is any national program of any nation which captures the imagination of its people, and the people of the whole world, for that matter, as does its space program.

Today the names of various spacecraft and astronauts are household words and are known around the globe. One reason for this unremitting popularity is that for the first time man is invading the heavens, a realm which, since the beginning of time, has generally been left to the vagaries of mystery, superstition, and religious speculation. A second reason is the heroism in a spectacular medium on the part of the astronaut. Heroism is a universal virtue, regardless of tongue, regardless of ideology. A third reason for this worldwide popularity is that any space feat, regardless of the nation that sponsors it, is looked upon by people throughout the world as mankind's assault on the unknown. It represents *man's* effort to conquer his environment and *man's* effort to understand the basic forces of Nature. It is for these reasons that accomplishments in space have had such universal propagandist value. I, personally, do not feel that the propaganda impact of significant space events on the peoples of the world has been overrated.

Every man harbors deep within him certain visions and dreams that he wishes could come true. I would like to share one of my personal dreams with you. I look forward to the day when mankind will join hands and face the heavens in solid phalanx to apply the combined technological ingenuity of all nations to the exploration and utilization of outer space for peaceful purposes. I applaud the efforts of the President of the United States—Lyndon Johnson today and John F. Kennedy before him—to encourage all nations to work together in the great adventure that is just beginning. Steps taken to date have been comparatively meager, but at least we have made a start. Would it not be ironical—as well as instructive—if nations first learn to transcend their national interests many, many miles away from Mother Earth?

This is but the dream. The realities of today's world sober us to the fact that our technological utopia in outer space has not arrived, and indeed may be a long way off. But I am convinced that the objectives of the National Conference on the Peaceful Uses of Space cannot be achieved until the scientists of all nations can work together in an atmosphere of mutual trust and unfettered cooperation. I believe our Nation should continue to work toward this goal without compromising its security, without sacrificing the best interests of its citizens.

I would like to return now to this harsh world of reality. In so doing, my combative instinct immediately becomes aroused because I want to discuss some of the conceptions, or rather misconceptions, about our space program prevailing among certain groups throughout the country.

The first misconception I would like to assault is the idea that the sole mission of the civilian space program is to put a man on the Moon. In the face of the multifarious mission accomplishments of our

satellites to date, it is astonishing that this misconception has been able to survive, much less be as prevalent as it is.

The variety and extent of the peaceful space activities of the United States are well known, and I need not catalog them here. Since 1958 when our first spacecraft, Explorer I, was launched, this country has embarked on a very broad-based space program. We have experienced a variety of spectacular space feats, and I should like to mention a few merely to make the point that the civilian space program is not a one-shot venture.

We all followed Mariner II making the 36-million-mile trip to Venus, passing within 21,000 miles of the planet, and radioing back to Earth important scientific information on its findings. Credit for this outstanding feat goes to D. William Pickering, Director of Jet Propulsion Laboratory. Some of us have enjoyed personally the benefits of other satellites, Telstar and Relay, by seeing clear transatlantic TV broadcasts and hearing telephone conversations. We all know of the Syncom satellite which travels in a synchronous orbit and introduces the era of the continuous worldwide satellite communications system. We have all benefited from the weather information provided by the Tiros weather satellite. We are all familiar with the orbiting solar observatory, which this very minute continues to provide knowledge about the emission of energy from the Sun.

Then there is the Manned Space Flight program. The Mercury program headed by Dr. Robert Gilruth has been completed successfully. Six Mercury spacecraft, each containing an astronaut, have been successfully launched and returned to the Earth. The names Glenn, Grissom, Shepard, Carpenter, Schirra, and Cooper have entered the lexicon of the Nation's heroes. Mercury accomplished its primary objective. It has demonstrated the ability of man to survive in space. It has proven that man is not a liability in outer space, but an asset, and that he can perform useful tasks in a space environment.

Coming up next in the manned-space-flight effort are the Gemini and Apollo programs. Extensive efforts are underway in both programs. Gemini will demonstrate that man can function in the space environment for prolonged periods of time. He will learn to maneuver his spacecraft, and to meet and physically join with other spacecraft in flight.

The Apollo program is even more ambitious. The Apollo spacecraft will be able to remain in orbit around the Earth for periods up to 2 months. It is the Apollo spacecraft which, after its performance is thoroughly proven in Earth orbit, will accomplish man's first landing on the Moon.

The manned programs suggest another question which has often been posed: What are manned spacecraft going to be able to do in the future, in terms of both peaceful and military missions, after the manned lunar landing has been accomplished? This question can be answered today only with another question: Who knows? We simply are in no position to make predictions here because our experience with men in space is so very, very meager. We have logged only 53 hours of space travel thus far, hardly enough to base predictions on anything more than pure conjecture. The only way we can answer this is to expose a lot of people to a lot of travel time in outer space, and then apply what these people have learned firsthand in their new environment.

This, of course, is not a novel approach. The modern concepts of air power were not developed in "think factories." These concepts evolved from the practical experiences of the brave young members of the Lafayette Escadrille and other flying groups in World War I, second lieutenants who actually took to the air and tried out such things as synchronized propellers, formation flying, instrument flying, and aerial photography.

And so it will be with manned space flight. As our astronauts log additional hours, hundreds and thousands of them, we shall learn many things from their experiences that will enable man to perform feats in the space environment that as yet have not even occurred to the mission planners back here in our Earth-bound think factories.

From the few random examples which I have listed of space achievements to date, it is obvious that our space program is moving forward on a very broad front. My purpose in stressing this fact is to meet head on the rather loose language one hears around the country, language which equates the "NASA Program" with the Moon program, language which constantly refers to the NASA appropriation as the "5-billion-dollar-man-on-the-Moon" budget. The Apollo project *is* NASA's largest project, but the story does not end there. Far from it. The program upon which NASA has embarked for the peaceful exploration and uses of space is the most versatile space

program employed by any nation on earth. I think the Nation should be aware of this fact and take pride in its accomplishments.

The next proposition I should like to discuss is the one that says we should abandon the space program entirely because we cannot afford it; or, as some would have it, reduce the level of effort to a level we can afford.

It is apparent that a program encompassing such a large variety of complex space activities requires for its accomplishments a major commitment of the Nation's resources. Today about 1 percent of the total income of the United States is devoted to the civilian space effort. In this decade, the United States will invest about $35 billion in its total civilian space program. About $20 billion of this will be devoted to the manned-space-flight effort.

In terms of manpower, the costs are equally high. Today, about one-quarter of a million people, both in Government and out, are working in the civilian space program. The bulk of these, about 200,000, are part of the Government-industry team for manned space flight.

In terms of facilities, the investment again is high. The space program involves far more than merely building large boosters and spacecraft. It involves capital investment in large engineering companies throughout the United States for fabricating, assembling, and testing the systems that comprise the launch vehicles and spacecraft. It requires investment in large environmental chambers, centrifuges, and simulators for preparation and training. It demands a worldwide tracking and data-acquisition network feeding into an integrated mission-control center. It requires a highly sophisticated launch complex, such as the Moon port being created as Cape Kennedy. When completed, these facilities will include some of the most massive and complex ground and engineering installations ever designed.

The question presents itself: Can the United States afford a program of such magnitude in the face of its continuing commitments to other national programs such as defense, agriculture, and welfare?

There are those who say that we should cancel this "Moon madness" and divert these space funds into more earthly projects, such as cancer research, aid to the needy, and urban redevelopment. Others say we should continue the program, but at a reduced annual level of effort in deference to these other programs. This latter theory holds that although it may take longer to get to the Moon, and although the total cost of the program will run higher, at the same time we shall be proceeding at a reduced *annual* rate of effort, a rate of effort the country can better afford.

My personal view is that we can afford to invest 1 percent of our annual gross national product in space. I believe that we can afford to continue to invest 4 or 5 percent of our annual Federal budget in the civilian space effort. I do not believe that if this budget were cut, any substantial increase would automatically accrue to these other programs—programs which, incidentally, I consider very worthwhile. Based on my own personal experiences before congressional committees, I do not believe that these annual appropriations are solely the result of fiscal finagling with figures, with funds being taken from this agency and applied to that agency, like some juggling act carried out under a master plan. I believe the approach taken by our elected officials is one in which each program must stand or fall on its own merits, as viewed by the American voter.

I believe the pace of our space program is entirely reasonable. Although the goals are ambitious and the schedules tight, it is not a crash program. We are moving forward vigorously, now that our immediate space goals have been clearly defined. I believe we are moving at a pace the American people expect, now that they have given the program their stamp of approval. There is no harm in setting one's goals high. This is the rigorous life. This is the American tradition.

I could not possibly take leave of you without briefly discussing the question which is probably put to me personally more often than any other. It runs something like this: We agree that the Nation should have a space program. We further agree that it should move forward on a broad mission front. But to do these things, why is it necessary to go to the Moon? Why can we not develop a space capability second to none through manned applications in near-Earth space, and forget this business about going to the Moon?

I think I can best make my point here by using an example. When Charles Lindbergh made his famous first flight to Paris, I do not believe anyone thought that his purpose in going was simply to get to Paris. If going to Paris had been his sole objective, he could have traveled by boat in much greater security and comfort. His purpose was more than personal transportation. His purpose was to demonstrate the feasi-

bility of transoceanic air travel—not to get to Paris, but to fly across the ocean. He could have selected a wheatfield in Alsace-Lorraine, or perhaps he could have landed in one of the moors in Scotland. But Colonel Lindbergh had the farsightedness to realize that the best way to demonstrate his point to his world audience was to select a target familiar to everyone. Everybody knew where New York was, and everybody knew where Paris was. The history books have recorded the immediate impact of his voyage.

Lindbergh achieved his objective, and today we are using air transoceanic transportation, not only to go to Paris, but to deliver cargo to Copenhagen, mail to Manila, and tourists to Tokyo, and, on selected occasions, to maintain the Berlin airlift.

In the Apollo program, the Moon is our Paris. We have selected a target familiar to everyone. Rather than asking the man on the street to accept the esoteric language of the trade, such as "rendezvous," "docking," and "orbital transfer," in defining the immediate objectives of man in space, the late President Kennedy selected a goal which is entirely familiar to the man on the street: sending men to the Moon before the end of this decade. The fellow next door knows what a man is, where the Moon is, and when this decade is out.

To prepare for this lunar trip, we shall have developed space vehicles with the versatility to perform all the orbital operations presently envisioned by this or any other nation. After the Moon is conquered, this versatile capability remains for other manned-space-flight applications, in both near and outer space.

The purpose of the manned-space-flight program, then, is to build an important national resource, a broad space capability, that will enable the United States to investigate and utilize the environment of space for a long time to come. It is providing the muscle which will undergird the Nation's posture in this newest dimension of national power—outer space.

I can illustrate this same point by treating it in terms of dollars. In this decade we expect to spend about $20 billion on the Manned Space Flight program. We consider that about 92 percent of this money, or well over $18 billion, is being and will be used to create permanent capital for the United States. Some of this permanent capital will be measured in terms of new technology, industrial manufacturing complexes, and governmental test and launch sites. But the greater part of this newly created capital will be the large numbers of highly trained technical people who will provide the nucleus of talent for the space missions following the lunar landing.

The other 8 percent of this $20 billion may be regarded as the consumables, as that part of the program which is used up in the process of developing this new capability. This includes such things as materials used up in ground tests, and the hardware and fuels that are actually launched into space.

I have saved until last the question which intrigues me most: Why invest in space at all? Money aside, is there really any purpose to be served by the space program?

To me, the question, "Why invest in space?" is the same as asking, "Why have an age of Science?" Man has been born an insatiably curious creature concerning his natural environment. And I think if there is any lesson man has really learned during the last 2,000 years of his violent history here on Earth, it is the fact that it seems to pay off handsomely, but often in the most unexpected way, to keep satisfying his curiosity about the world around him. The only restraints upon his satisfying this innate curiosity, now that he has shed the shackles of superstition and myth, have been the lack of the proper tools, such as the microscope, telescope, bathysphere, or spacecraft to enable him to carry his investigations further and his probes deeper.

In today's explosion of technology, man is rapidly developing these tools. He is rapidly developing the capability both to explore the Earth more thoroughly and to explore the celestial environment that surrounds him. And because he is developing the means, man will follow his natural nosiness and will capitalize on his opportunity to investigate and uncover new phenomena of nature. He will, and should, apply these tools to firsthand observations of the environment of space.

Indeed, this is what we have already set out to do. For the first time, we are in a position to examine and measure the Sun. For the first time, we stand on the threshold of determining the origin and nature of the solar system. And we have already demonstrated our ability to use this new space environment for practical purposes, such as communications and weather observation.

These are the questions that I wanted to discuss with you.

Time permitting, there are many other noteworthy aspects of our space program that I should have liked to discuss. There is the subject of the very bene-

ficial impact the program has had on the American economy, in all sections of the United States. There is the vast subject of program management, and the managerial revolution that has swept the country to find adequate means to marshall the varied, dispersed talents of our Government-industry team in massive array to accomplish mammoth projects such as the Apollo program. Literally thousands of private business, both large and small, are participating in the Apollo program alone.

I also could have discussed the contribution that the civilian space program is making to higher education, and the stimulus it has provided to the research programs of our universities and the training of our young scientists and engineers. I could have discussed what we are doing in NASA to transfer to the industrial sector of our economy the results or "spin-off" of our space-oriented research that may have application as new tools, devices, materials, processes, and techniques of benefit to the American consumer in everyday life.

And, finally, I could have discussed some of the tangible steps that this country, represented by some of our own high-ranking officials in NASA, notably Dr. Hugh Dryden, have taken with other nations regarding international programs for the peaceful uses of space.

I have avoided all these subjects because I feel that the basic questions, which I have discussed, command priority attention. It is these questions that reach to the vitals of our entire space effort, and it is these questions that must be answered, if this country is to have an adequate space program, or, indeed, if this country is to have a space program at all.

The United States has made monumental strides forward into the Space Age. At the same time, we have hardly begun. The present phase of our space program brings to my mind an earlier period in the history of the Western World, the period when man first laid the great foundation, both in thought and achievement, for the better world we enjoy today.

I speak of the Renaissance. I speak of the era of Michelangelo and Da Vinci, the era of Shakespeare, Cervantes, Raphael, and Rabelais. It was in this period, beginning in the 15th century, that man took his first great strides forward to emancipate himself from his environment, when man first undertook the conquest of the planet Earth as a place of human occupation.

The Renaissance is often called the Age of Discovery, the age when men summoned forth their courage and set out on the high seas to explore the four corners of the Earth. It was the age of Sir Walter Raleigh and Sir Francis Drake. It was the age of Columbus, Diaz, Pizarro, and da Gama.

We have not yet entered the Second Age of Discovery, the exploration of outer space. We are still in the harbor. We are still building and checking out the seaworthiness of our craft. We are still learning the things we need to know about the new medium through which we shall have to travel. The Mercury astronauts were not the explorers. The Mercury astronauts were the test pilots, but they did not leave the harbor of Mother Earth.

But we do stand on the threshold of the Second Age of Discovery. When the craft is ready and the oceans of space are calm—calm because we have learned the new medium and have prepared to sail on it—the new explorers will venture forth. The Space-Age Columbus and Magellan are presently unknown, but they are sitting somewhere today in a public schoolhouse preparing for an adventure that exceeds the wildest daydream which today distracts them from their books.

These are the beneficiaries of our crude efforts today. Here are the people to whom we shall pass the baton. But the first lap of the race is ours. And we shall not falter.

MACHINES IN SPACE

Chairman
JOHN V. HARRINGTON
Director
Center for Space Research
Massachusetts Institute of Technology

INTRODUCTION TO

MACHINES IN SPACE

JOHN V. HARRINGTON
Director
Center for Space Research
Massachusetts Institute of Technology

Our session is designated *Machines in Space,* but perhaps its more fundamental concern is the scientific exploration of space. In the previous session, we learned of the major and very impressive efforts that have been mounted and will continue to be mounted for the manned exploration of space. In fact, we learned that the major portion of the space budget has been granted to this purpose.

In contrast with this, however, it is only fair to say that most of the impact on man's knowledge of the near-solar system has resulted from the unmanned space exploration program and comes overwhelmingly from the multiplicity of unmanned spacecraft, probes, and sounding rockets which have been flown in the past 5 to 7 years. The data coming from these machines caused scientists to reshape, in quite radical ways, their views about the space environment near Earth, and, indeed, on much of the near-solar system. In this session will be discussed some of the details of how this has been accomplished. Various men who in different ways have contributed very heavily to the growth of space science and scientific space exploration will outline the projects underway to explore this environment, the Moon, the planets, and the near-solar system, and, most important, to pinpoint the major discoveries that have come from the program thus far. The machines for unmanned exploration vary in complexity from the very simple earth orbiters of 7 years ago (as exemplified by, say, Explorer I which carried but a few simple measuring instruments) to spacecraft of very considerable sophistication (such as the orbiting observatories which are capable of carrying a great variety of complex scientific instrumentation and of being controlled to a very considerable degree by experimenters on the ground). The most difficult of any of these unmanned explorations, of course, occurs in the investigation of the planets where the technological problems of guidance of the craft and information handling are formidable. Even here, however, in spite of the very short history of the national Space Program and the very great difficulty of planetary exploration and lunar exploration by this unmanned means, the Mariner II exploration of Venus indicates what can be accomplished.

EXPLORING THE MAGNETOSPHERE*

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The preliminary exploration of the magnetosphere and its immediate surroundings is rapidly being completed. The description that is being obtained with the help of satellites and space probes enables us to define the space environment accurately but usually empirically. That is, our knowledge of the physical properties of the space environment is becoming more precise, but our theoretical understanding of what we observe has not yet made corresponding progress.

For example, we now have a reasonably complete description of the time-dependent energy spectrum of the particles that constitute the Van Allen radiation. However, there is no adequate explanation for this radiation although 6 years have passed since its discovery. Similarly, the aurora, which has been observed and pondered since prehistory, is yet to be understood.

On the other hand, our understanding of the gross configuration of the magnetosphere and its shape in the solar wind appears quite adequate. Thus, while the exploration of the magnetosphere has led to some gratifying progress in our understanding of the space environment, many outstanding problems remain.

*Dr. Dessler furnished this summary to be published in lieu of the full text of his paper.

N64-30337

EXPLORATION OF THE MOON AND PLANETS

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One of the first things that Galileo did when he discovered that two lenses make a telescope was to look at the heavens. He described the mountains on our Moon and the moons of Jupiter. He observed the phases of the planet Venus. He began the exploration of our Moon and the planets.

Since his time, telescopes have improved in size and capability. New types of instruments have been attached to them, and new instruments, such as radio telescopes, have been used to extend our knowledge of the solar system. With the aid of this host of instruments here on the surface of the Earth, we have learned a great deal about the Moon and the planets. We know their orbits, their sizes, their temperatures. We know something about their atmospheres, and in a few cases we have some vague notions of their surface markings.

We have come a long way from the myths and legends of classical times and have put aside most of the superstitions of astrology. But now, with the development of powerful rockets, we are truly standing at the threshold of the real exploration of the Moon and planets.

The elementary physics of sending instruments, or man, to a nearby planet involves many problems. Figure 1 shows a portion of the solar system approximately to scale. Figure 2 (distances to the planets) illustrates the distances from the Earth to some of the planets as a function of time. Venus, Mars, and Mercury come within less than 100 million kilometers of the Earth; Jupiter is much further away. To travel to even the nearest planets, we must consider voyages of many tens of millions of kilometers.

The first problem is to accelerate the spacecraft sufficiently to escape from the Earth's gravitational pull. From a point near the surface of the Earth this requires a speed of about 7 miles per second. When it has climbed out of the Earth's field, the spacecraft is in the gravitational field of the Sun and perhaps the Moon. Its motion is determined by its remaining velocity (relative to the Earth), which will be quite small unless its initial speed was much greater than 7 miles per second, combined with the velocity of the Earth in its orbit around the Sun. This latter speed is about 19 miles per second, so the spacecraft speed relative to the Sun will not differ greatly from that of the Earth. Therefore, as seen from the Sun, the spacecraft will be in an orbit which is approximately an ellipse with its perihelion or aphelion on the Earth's orbit depending on whether the spacecraft velocity is greater or less than that of the Earth. If the initial conditions are correctly chosen, this ellipse may then be used to transport the spacecraft to a close encounter with another planet.

To send a spacecraft to the Moon, we can consider the situation as being approximately one in which the Moon is rotating around the Earth, and the effect

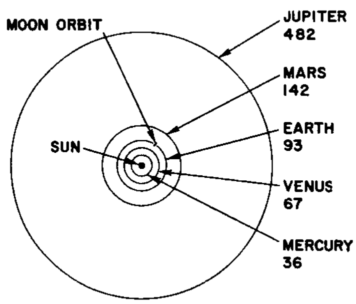

FIGURE 1.—The solar system (distances from Sun in millions of miles).

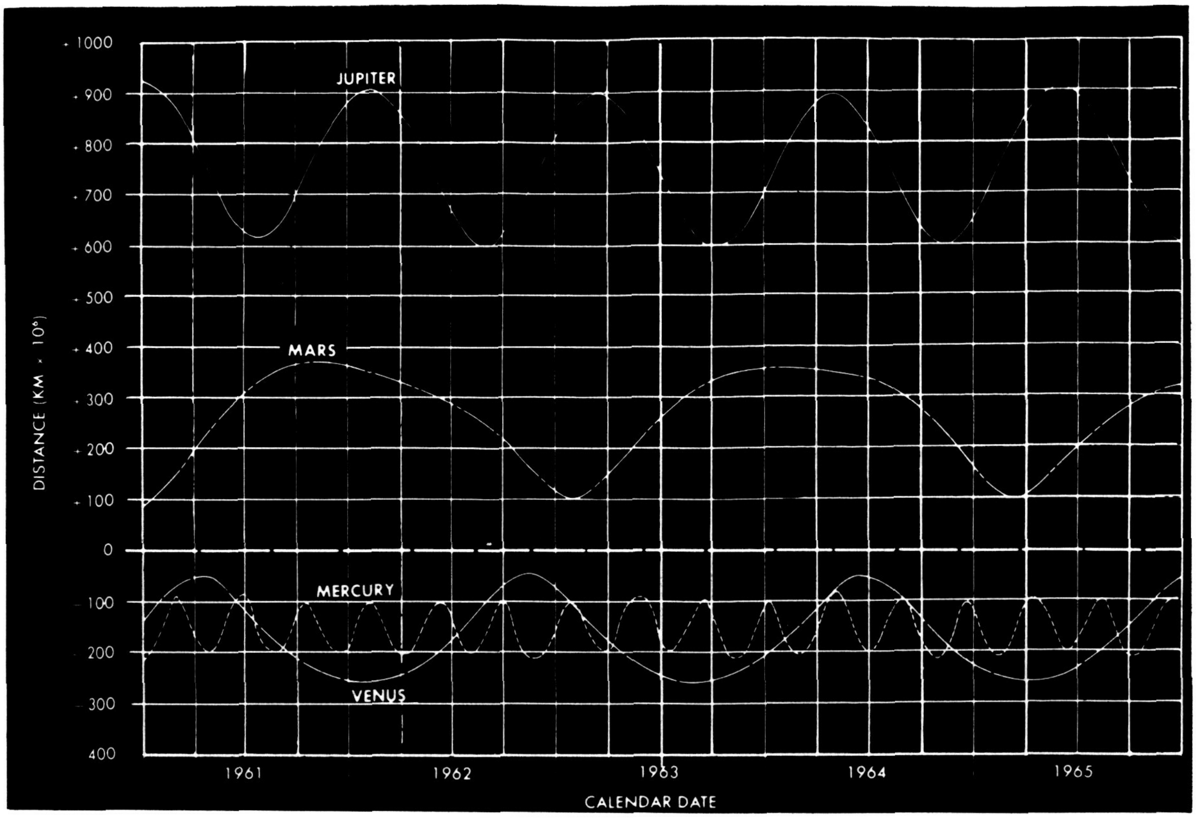

FIGURE 2.—Relative planet distances and periods.

of the motion of the combined system around the Sun can be neglected. The spacecraft must, therefore, leave the Earth on a trajectory which carries it close to the Moon. It will then come under the influence of the Moon's gravitational field and be pulled towards the Moon. The actual path must be computed as a solution to the problem of the motion of a particle in the gravitational field of the two attracting bodies, with minor perturbations from the other members of the solar system.

The speed of a lunar spacecraft when near the surface of Earth may be somewhat less than escape speed. In fact, the orbits used by both the United States and Soviet Moon probes have been elliptical orbits around the Earth with the apogee at a point lying beyond the Moon's orbit.

As a measure of our present capability to send spacecraft into deep space, Table I shows the performance of several U.S. rockets as measured by the payloads which can be accelerated to escape velocity.

For comparison, the Soviet payloads sent to the Moon or beyond include Lunik I in 1959 (800 pounds), the Venus attempt of February 1961 (1,400 pounds), the Mars attempt of Nevember 1962 (1,980 pounds), and Lunik IV attempt in April 1963 (3,100 pounds).

TABLE I.—*Payload performance*

	Pounds that can be sent to—		
	300 nautical miles	Escape velocity	Mars/Venus
Delta	800	105	90
Atlas/Agena–B	5,000	750	400
Centaur	8,500	2,300	1,300

With this capability of sending relatively small payloads far out into the solar system, several types of experiments can be considered. (This discussion is based on the assumption that we have the capability

of guiding the vehicle close to the target object, and of communicating with it while it is at the target.)

We can visualize three types of missions. The simplest is a "fly-by." The spacecraft passes close to the target and makes observations as it goes by. These observations may be stored for later transmission to the Earth, or sent back in real time over the radio circuit. The Soviet pictures of the back side of the Moon were taken as the spacecraft flew past, and then developed and transmitted to the Earth at a later time. The U.S. Mariner spacecraft to Venus transmitted its data in real time as it flew past the planet.

The next type of mission is an orbital mission. In order to be captured into an orbit around the Moon or a planet, the spacecraft must lose kinetic energy. Hence, either a retrorocket must be carried, or it must skip through the atmosphere of the planet and lose sufficient energy by friction. Practically speaking, the retrorocket solution is the only one considered at this time. An orbiting spacecraft can, of course, make a

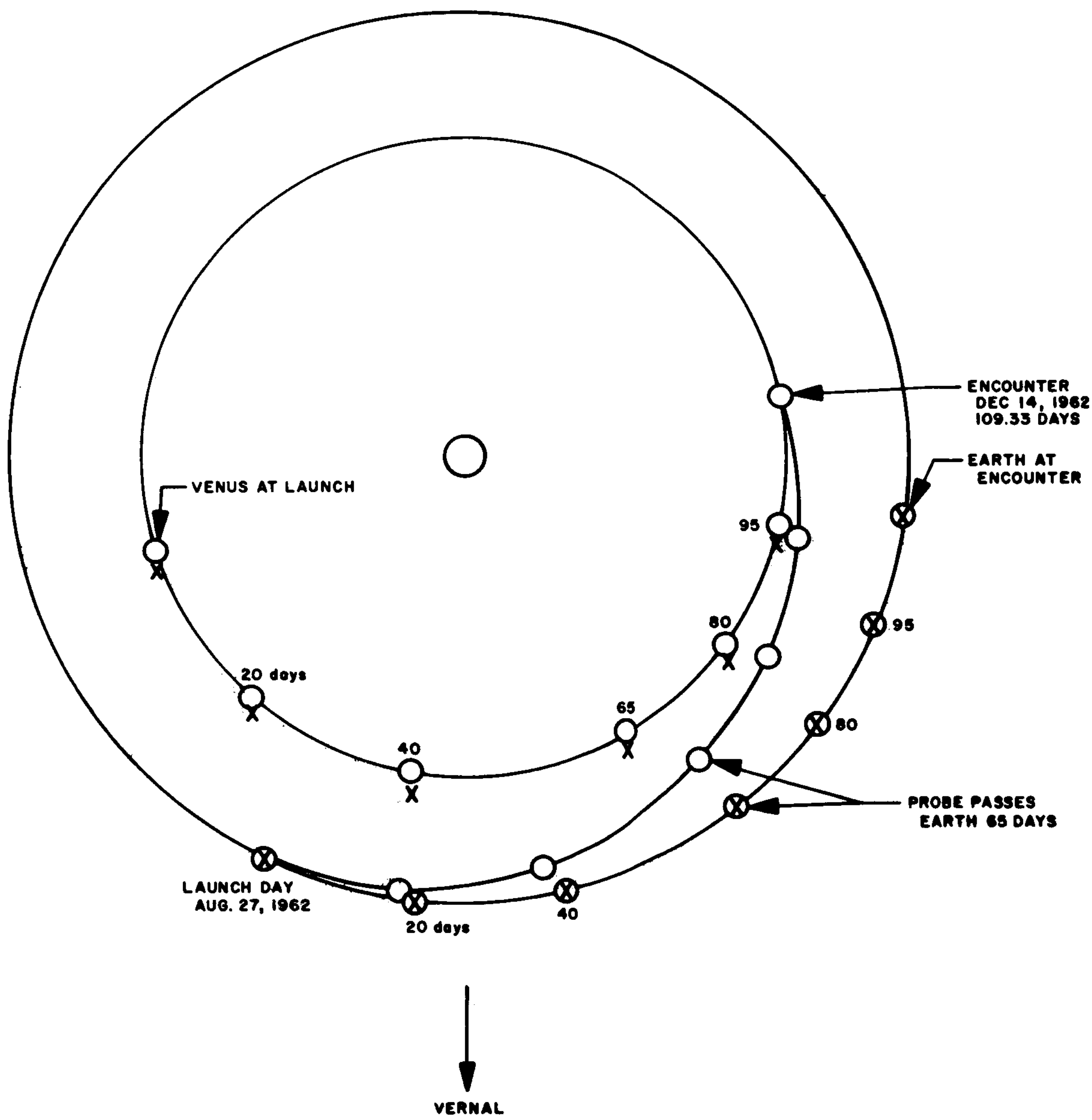

FIGURE 3.—Heliocentric plan view of trajectory of Mariner II Venus probe.

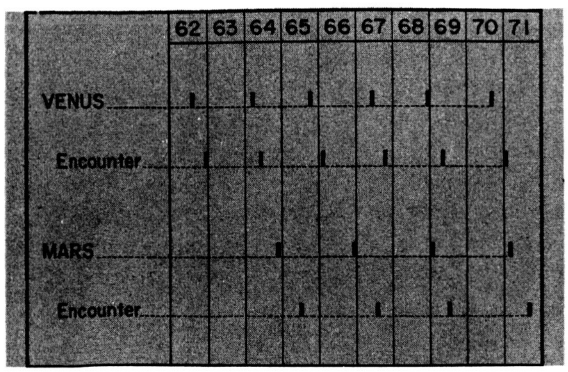

FIGURE 4.—Planet availability.

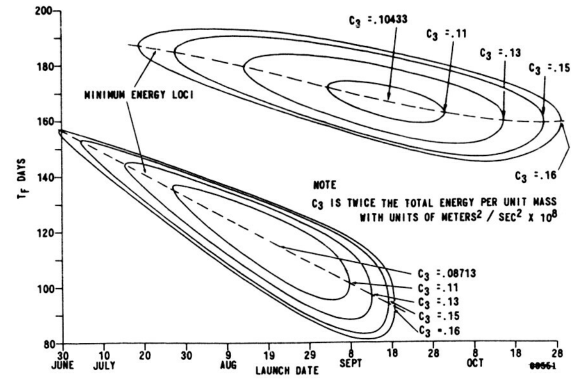

FIGURE 5.—Increase in energy as launch day departs from optimum (availability of Venus in 1962).

more extensive series of observations than a simple fly-by; however, the observations will be basically of the same type. When the orbit can be closely controlled, the distance may be made quite small or the spacecraft may be made to travel through some interesting region such as radiation belts or an ionosphere.

The third type of mission is the entry or landing mission. Again, the spacecraft must lose kinetic energy if it is going to reach the surface at zero speed. If the target has no atmosphere, retrorockets must be used; if there is an atmosphere, aerodynamic braking probably will be a better answer. The entry vehicle can perform two classes of missions, atmospheric measurements during descent and surface observations after landing. Detailed exploration of a lunar or planetary target will certainly have to wait for entry and landing missions.

Instead of a discussion of the scientific details or objectives of lunar and planetary exploration, this is a review of some of the engineering problems which must be solved if an unmanned spacecraft is to be sent to another planet. We can visualize the elements of an exploration program of a whole new world, but there are many engineering problems which must be solved first. Actually, our rocket and spacecraft technology is still in the stage where engineering developments far exceed in cost and complexity the purely scientific developments necessary to carry out the missions.

As noted earlier, the spacecraft is required to move on a trajectory that is a section of an ellipse passing through both the Earth's orbit and the orbit of the target planet. The motions of Earth and planet are known from astronomical data. Therefore, the trajectory must be calculated so that the spacecraft will leave the Earth with the correct velocity and direction to arrive at the orbit of the target coincident with the target planet. A typical example of such a trajectory is shown in figure 3, which is the trajectory of the Mariner Venus probe. Since the motions of Earth and planet are determined, it is clear that launchings can take place only at limited times. Figure 4 shows these times for launchings to Mars and Venus; the exact length of the launch period at a permissible time depends upon the energy available with the launching rocket. Figure 5 illustrates the increase in energy as the launch day departs from the optimum; travel time is plotted against launch date for two types of trajectory and parameter C_3 is a measure of the spacecraft energy required.

Thus, we have one engineering constraint imposed on a planetary mission, namely a nonslippable launch schedule. On any one day in the launch opportunity there will be a short period of about 1 hour during which a launch may be conducted from Cape Kennedy. This constraint is determined by the permissible launch azimuths from the cape and the limitations of range instrumentation. The maximum flexibility is obtained by using a so-called "parking orbit" where the spacecraft is placed in a low Earth satellite orbit until it has traveled to an appropriate point on the Earth's surface, at which time it is accelerated up to its escape speed.

In order to attain the desired orbit, it is obvious that the spacecraft must be guided with a very high degree of accuracy. The launching rocket must be capable of being fired on a path which varies with the exact moment of launch and which places the space-

craft, together with the final stage rocket, on a predetermined satellite orbit. During the coasting phase of this orbit, the final stage rocket must be correctly oriented so that its thrust will be in the correct direction to achieve the desired final velocity. The exact instant of initiation of this final burning and the final velocity will likewise be determined by the moment of launching.

Theoretically, the launch-rocket guidance system could be made sufficiently accurate to attain the desired trajectory. However, in practice it is much more reasonable to place a somewhat relaxed requirement on the initial guidance and to carry aboard the spacecraft a small rocket which can be used to make a correction to the path.

This *midcourse* guidance requires a precise knowledge of the actual trajectory, which can be obtained by radio tracking stations on Earth and a calculation of the desired vector velocity change to bring the spacecraft on course. The spacecraft must then be maneuvered into a calculated attitude, and the rocket motor turned on to give the desired velocity change. Figure 6 illustrates such a maneuver, as used with the Mariner spacecraft. The requirement for accurate guidance, therefore, places additional constraints on the spacecraft. Its attitude must be controllable, it must carry a controllable rocket motor, and it must be able to accept radio commands.

A third class of constraints associated with a planetary mission is that associated with the vast distances to be traversed. A voyage to Venus requires about 3½ months and the spacecraft is 36 million miles distant from the Earth when it reaches the planet. To travel to Mars requires about 8 months, and the distance to the planet is more than 100 million miles. Hence, the spacecraft equipment must be designed to operate properly in the space environment for these long periods. Furthermore, it must be able to communicate over these distances of tens of millions of miles.

Because of obvious limitations of available power and antenna size, communication systems for planetary spacecraft must be designed to perform very close to ultimate theoretical capability. Even so, the information from a spacecraft near another planet is very low. Near Venus, Mariner provided only 8⅓ bits per second. Therefore, the scientific or engineer-

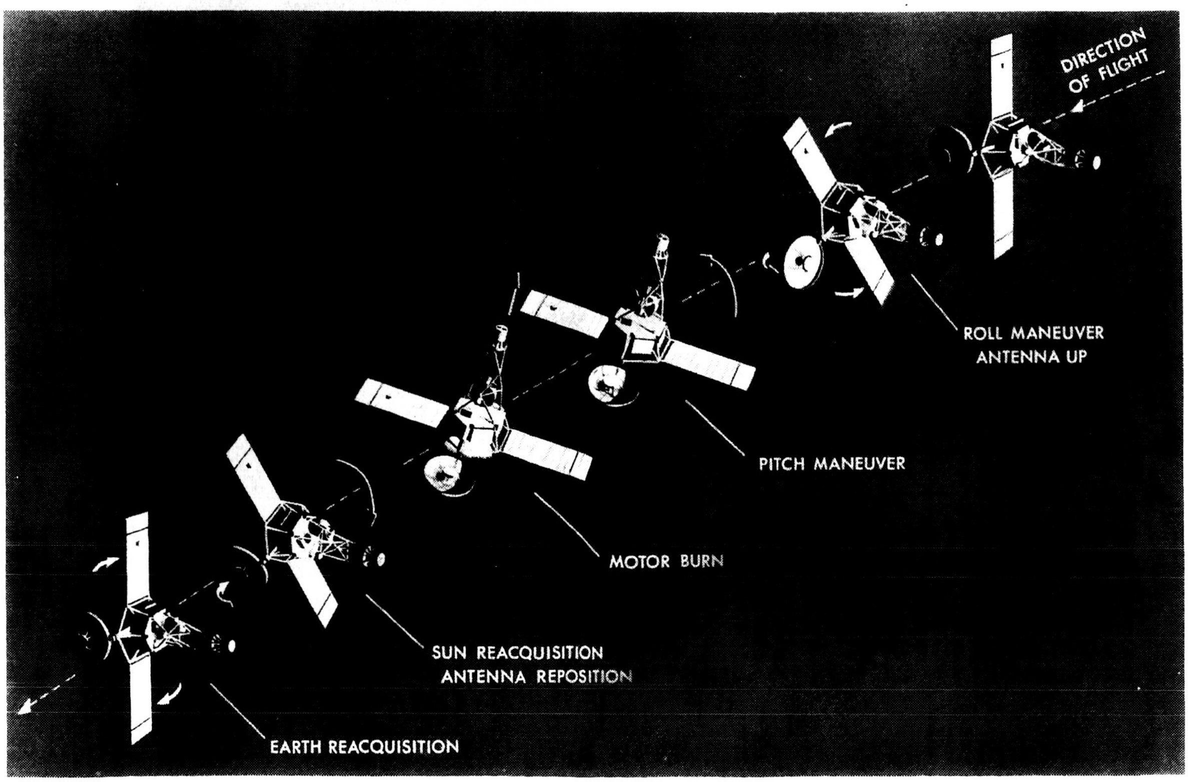

FIGURE 6.—Mariner midcourse maneuver.

ing data which is to be sent back to Earth must be carefully processed before transmission, and the rate at which a measurement is sampled must be kept as low as possible. In the Mariner shot to Mars at the end of this year, it is hoped to include a television system to take some closeup pictures of the planet. However, the low data rate (in this case, also, $8\frac{1}{3}$ bits per second) requires that the pictures be stored and transmitted over a period of about 1 day for each picture.

The actual implementation of a planetary mission can be illustrated by the Mariner flight to Venus. The boost-rocket performance permitted a total spacecraft weight of 450 pounds. It was determined that guidance capability to fly by the planet within about 20,000 miles with communication capability to send a reasonable amount of scientific data back to earth was within the state of the art. A group of scientific experiments to provide both cruise data en route to the planet and planetary data while passing the planet were selected. The Jet Propulsion Laboratory was assigned the task. Figure 7 shows the result, Mariner II, which successfully carried out its mission.

It was obvious almost from the beginning of the Mariner project that the permissible weight would require very careful design of the structure and careful integration of all elements of the spacecraft into an optimum configuration. The structure selected was a hexagon with the spacecraft electronics distributed in boxes around the hexagon. One instrument, the magnetometer, had to be placed as far as possible from the electrical circuits, hence a lightweight tower structure above the hexagon carried this instrument.

A parabolic directional antenna was needed to communicate back to Earth. Since this had to be contained within the internal dimensions of the nose shroud of the launching rocket, it was conveniently nested at the base of the hexagon. A midcourse motor was needed to correct the course to the desired close encounter with Venus. This was placed along the axis of the spacecraft inside the hexagon.

Finally, solar cells were selected to generate electrical power during the flight. These cells covered two solar panels which could be folded up alongside the spacecraft during the launch phase. Hence, the

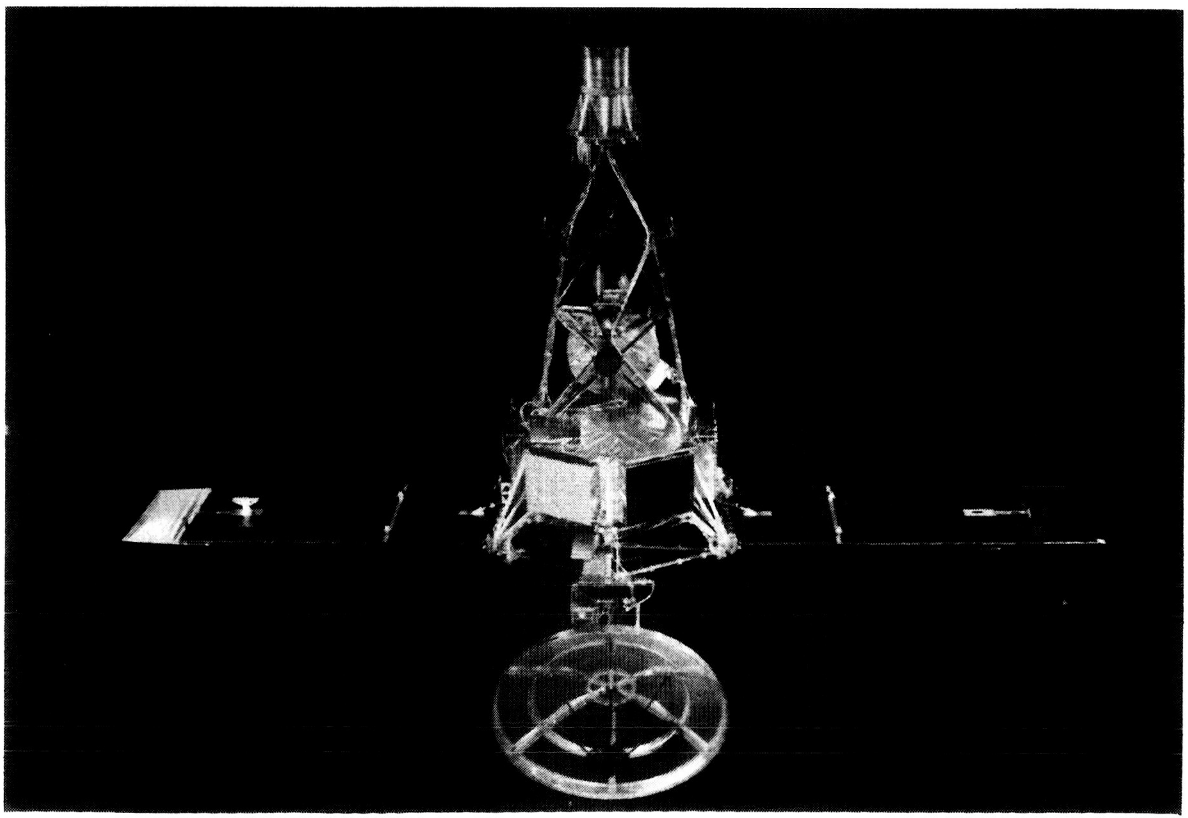

FIGURE 7.—Mariner II.

basic elements of the structure were defined. The scale of the device was adjusted to fit the Agena launching rocket, and the weight was constrained to be within the 450 pounds permitted.

Of the various subsystems making up the spacecraft, the science instruments can be divided into the cruise science and the encounter science. Cruise science included measurements of the interplanetary environment, radiations, magnetic fields, and micrometeorites. Encounter science added two infrared and 2-millimeter wave radiometers to scan the planet as Mariner flew past. These last instruments were mounted on a platform which was designed to scan about one axis so that the radiometers would sweep across the planet. Clearly the guidance accuracy had to be such that Mariner would pass the planet in a limited region where the instruments could collect data. Furthermore, the attitude stabilization had to be precise to ensure that the instruments would actually see the planet. A means had to be provided to switch on the encounter science experiments at the correct time. Actually, two switches were used, one turned on by an internal clock and the other by a radio command from Earth.

Data from the various science instruments had to be collected and processed for transmission to Earth. The various scientific and engineering measurements, about 100 in all, were, therefore, divided in a time-sharing scheme that sampled some measurements as frequently as once every 20 seconds and others as infrequently as once every 4 hours.

The communications subsystem consisted of a transmitter to send telemetry information back to Earth, a receiver to receive signals from Earth, and a decoder to

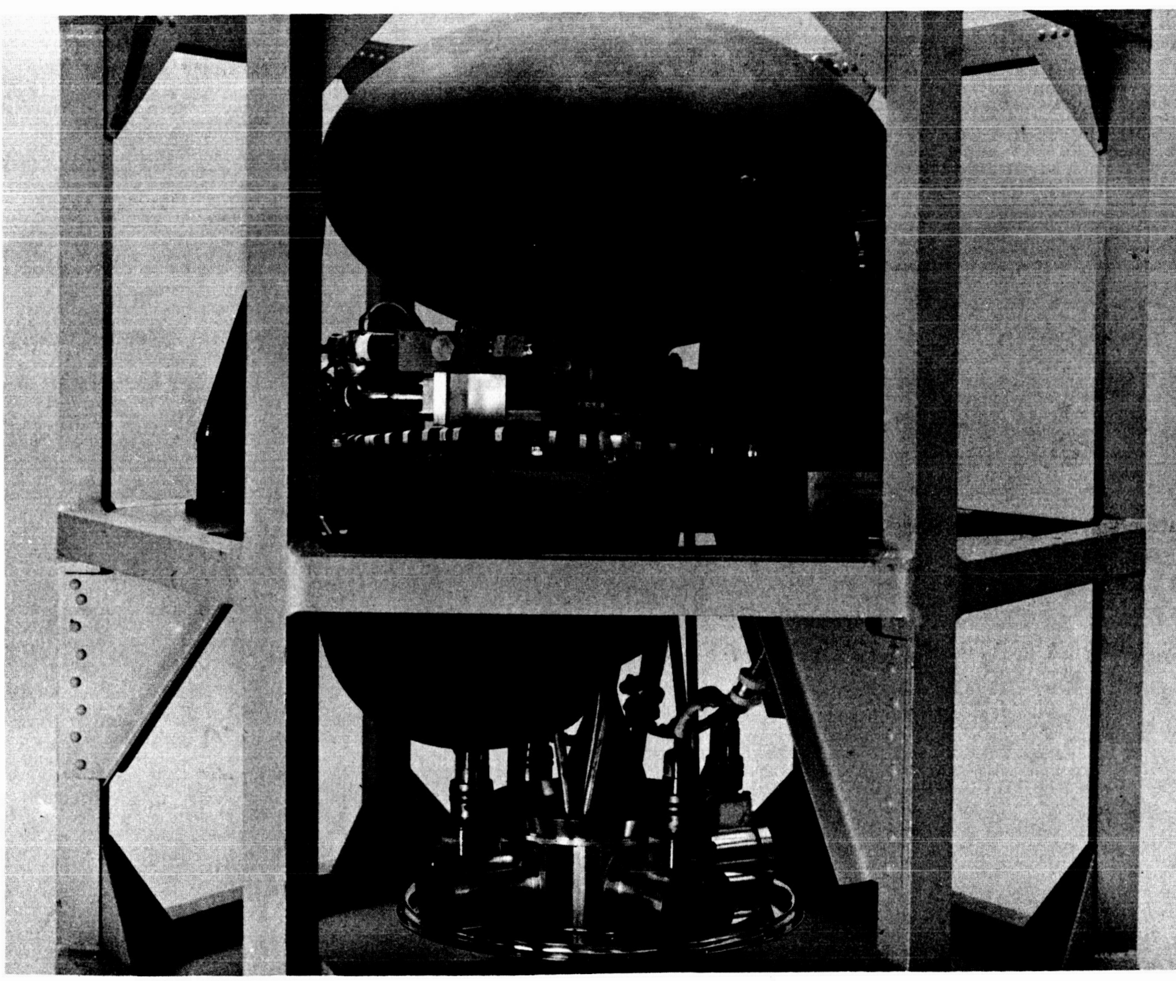

FIGURE 8.—Midcourse motor of Mariner II.

separate out command information from Earth. The transmitted signal was locked in frequency to an integral fraction of the received frequency, so that doppler information could be received on the earth. Three antennas were used: a command-receiver antenna, an omnidirectional-transmitter antenna, and a parabolic antenna which was kept pointed at the Earth except during spacecraft maneuvers.

The attitude stabilization system was used in two different ways. During the cruise period a Sun seeker kept the long axis of the spacecraft pointed at the Sun; an Earth seeker kept the axis of the parabolic antenna pointed at the Earth. In order to do this, the spacecraft rolled around the Sun axis, and the antenna hinge angle was adjusted to the correct value. Motion of the spacecraft was accomplished by small cold gas jets operated through a relay servosystem. During the midcourse maneuver, the attitude was measured and controlled by gyroscopes which were run up to speed shortly before the maneuver. When the rocket engine fired, jet vanes in the exhaust were used to develop appropriate correction torques.

Power for the spacecraft came from the solar panels. A battery was used during the launch phase and during the maneuver phase when the solar panels were not alined normal to the Sun. Because of the doubling of solar intensity between the Earth and Venus, the power system had to be designed with appropriate regulation and stability. The power consumption during cruise was about 150 watts.

The midcourse motor (fig. 8) was a monopropellant hydrazine motor with 50 pounds thrust, which could be run for periods as short as 2/10 second or as long as 57 seconds. The duration of motor burn during flight was determined by an integrating accelerometer which measured and compared the actual velocity change against the commanded velocity change.

One of the interesting engineering problems in a spacecraft is that of temperature control. In the vacuum of space, heat energy enters or leaves the spacecraft only through radiation. Hence, the radiating properties of the surfaces of the craft are vitally important. Mariner controlled the temperature throughout the vehicle by means of appropriate surface treatments. Paint patterns, aluminum sheet, gold plating, and polished surfaces were all used. Thermally controlled louvers were also used on one electronic box.

During the actual flight, the temperature control was not quite as good as expected. Temperatures were higher than anticipated, and towards the end many electronic components had exceeded their design temperatures. However, no serious difficulties occurred until about 3 weeks beyond the planet.

This brief description suggests some of the engineering problems which must be solved for a spacecraft of this type to fulfill its mission. It is clear that electronic devices are of tremendous importance. These devices fall into two broad classes: First, the various elements of the communication system, including the modulation circuitry required to convert instrument signals into an appropriate form for transmission and, second, the computing and other circuitry associated with the guidance problems.

Mariner demonstrated what can be done with modern electronic engineering. Much of the electronic design for the spacecraft grew directly from fundamental research done at the Jet Propulsion Laboratory during the past 10 to 15 years. As an example of the efficiency of modern communication systems, the transmitter on the Mariner spacecraft radiated only 3 watts of power, yet it successfully sent back data when it was more than 50 million miles from Earth.

On the Earth's surface, three receiving stations were

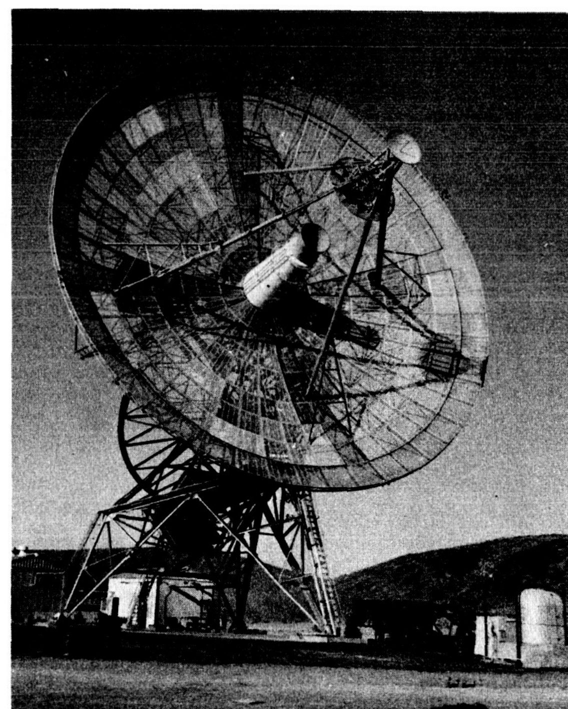

FIGURE 9.—Parabolic 85-foot antenna at Goldstone, Calif.

TABLE II.—*Illustrative communication systems*

	Earth satellite	Lunar orbiter	Lunar lander	Mars orbiter	Space probe
Range, km	4×10^3	4×10^5	4×10^5	4×10^8	4×10^{10}
Earth antenna gain, db	10^3	4×10^4	10^6	10^6	10^6
Vehicle antenna area, m^2	0.05	7	2.5	100	100
System temperature, °K	400	220	400	100	100
Vehicle radiated power, watts	200	50	10	150	150
Bandwidth (for S/N = 10^3 watts/watt), cps	4×10^6	10^6	10^6	2.5×10^3	2.5×10^{-2}

used. These employed 85-foot-diameter parabolic antennas located in California, South Africa, and Australia so that at least one station was always observing the spacecraft. Figure 9 is a photograph of one of the 85-foot antennas at Goldstone, Calif. Data from each station in the system are recorded on magnetic tape at the station and also sent to the central control point in Pasadena where they are decoded and presented in analog and digital form as necessary.

Table II illustrates the performance of typical space communication systems built with such equipment. The last line in the table gives the band-widths which

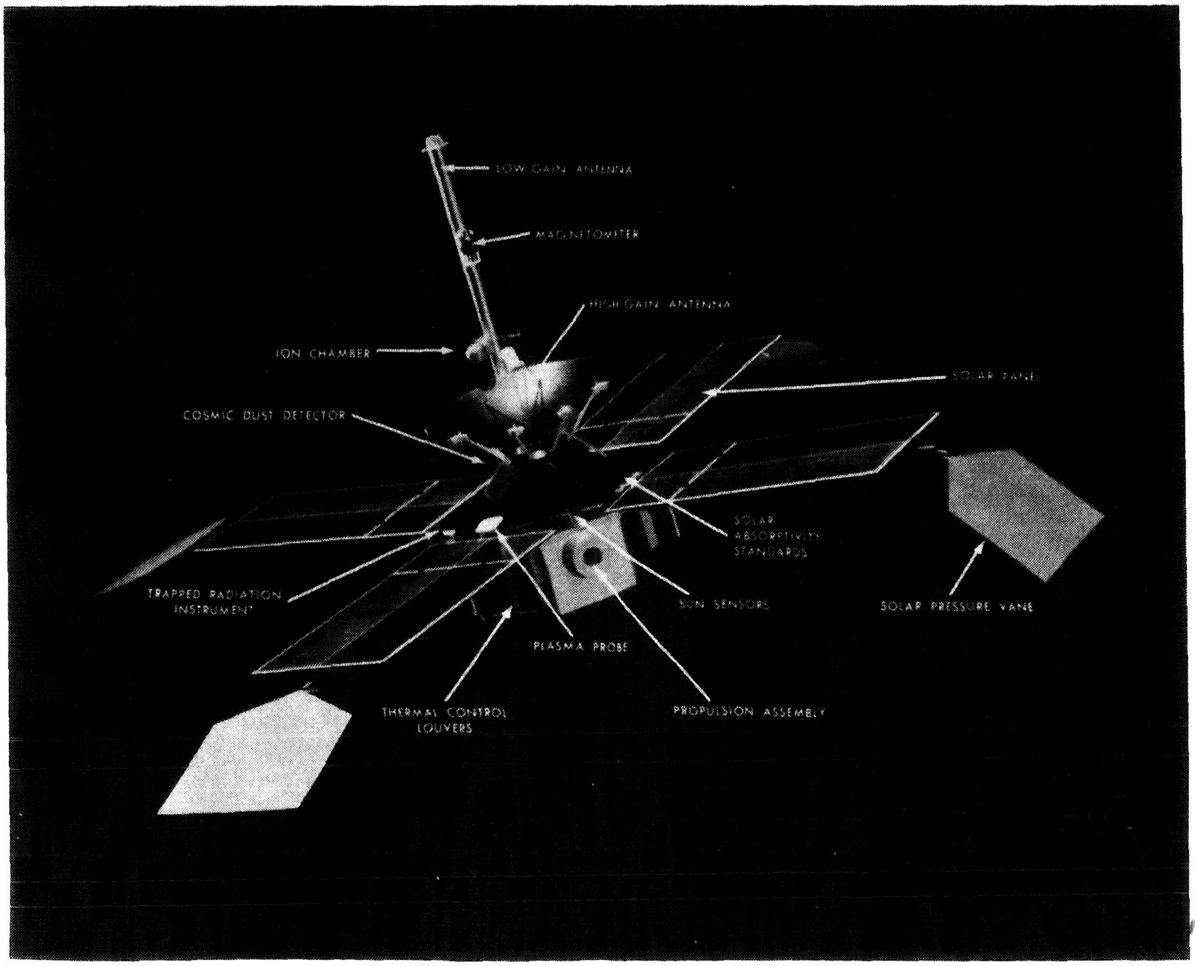

FIGURE 10.—Model of Mariner for November 1964 mission.

are attained using the parameters listed. It is obvious that television signals from the Moon can be obtained, and signals can be received out to the edge of the solar system.

As the next step in planetary exploration we intend to launch a Mariner spacecraft to the planet Mars during the opportunity in November of 1964. Figure 10 is a photograph of a model of the Mariner for this mission. It has a family resemblance to the Venus spacecraft but differs in several important details. For example, there are four solar panels, each carrying a solar vane at its outer edge. These solar vanes are designed to take advantage of solar radiation pressure to assist in stabilizing the vehicle. The vanes are connected to the attitude control system and operate in a manner similar to the trim tabs of an airplane. The high-gain antenna is fixed to the spacecraft structure. This can be done because the Sun-spacecraft-Earth angle remains nearly constant for a large part of the mission. The spacecraft is stabilized by using the Sun for one axis and the star Canopus for the other. The midcourse propulsion system is oriented at right angles to the Sun axis of the spacecraft instead of being directed along this axis as in Mariner II. The electronic components are distributed in boxes arranged on an octagonal structure. Thermal control is with light metal louvers which change the thermal radiating properties of the surface.

Figure 11 is a photograph of Ranger, our current lunar spacecraft. This particular version of Ranger, the Block III, is designed to take closeup television pictures of the Moon. Again the design is very similar to Mariner. The television cameras are con-

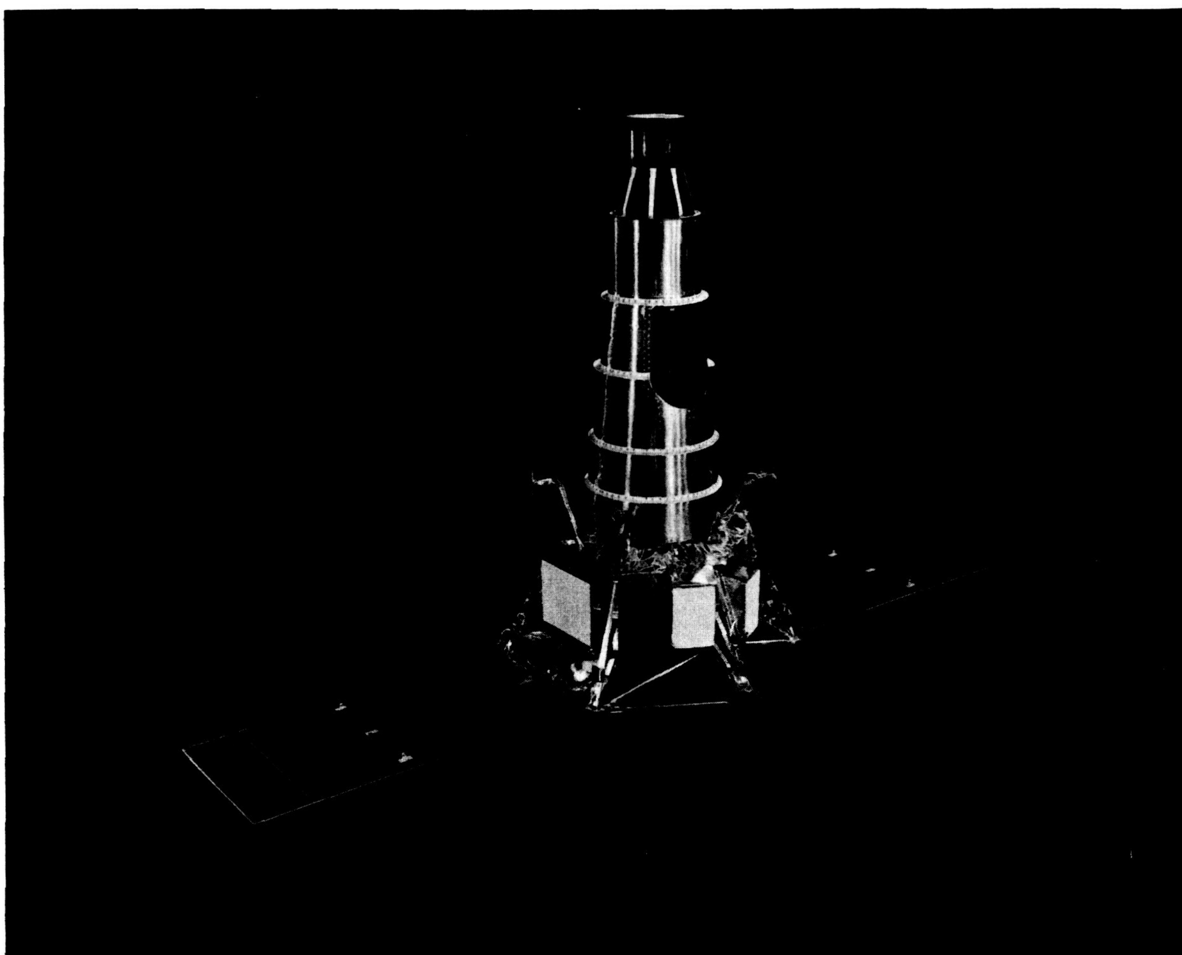

FIGURE 11.—Ranger.

tained in the conical structure above the hexagon. A set of six cameras, divided between two independent transmitters, looks out of the side of the cone. The spacecraft is oriented so that, on approaching the Moon, the cameras are looking along the velocity vector.

There are four Block III Rangers. The first, launched on January 30, 1964, succeeded in landing on the Moon very close to the specified target, as shown in figure 12. However, the television system failed, and no photographs were taken. The next in the series will be launched in the summer of 1964.

If we consider the broad problems associated with this unmanned exploration of the solar system, it is clear that the engineering design of systems which will meet the constraints of weight, volume, power consumption, and life in the space environment is most important. The next problem is that of manufacturing components and assemblies to meet the standards of performance and reliability required for these expensive missions. As we are able to solve these problems, so will we extend our knowledge far out beyond our Earth. This is the challenge which we face.

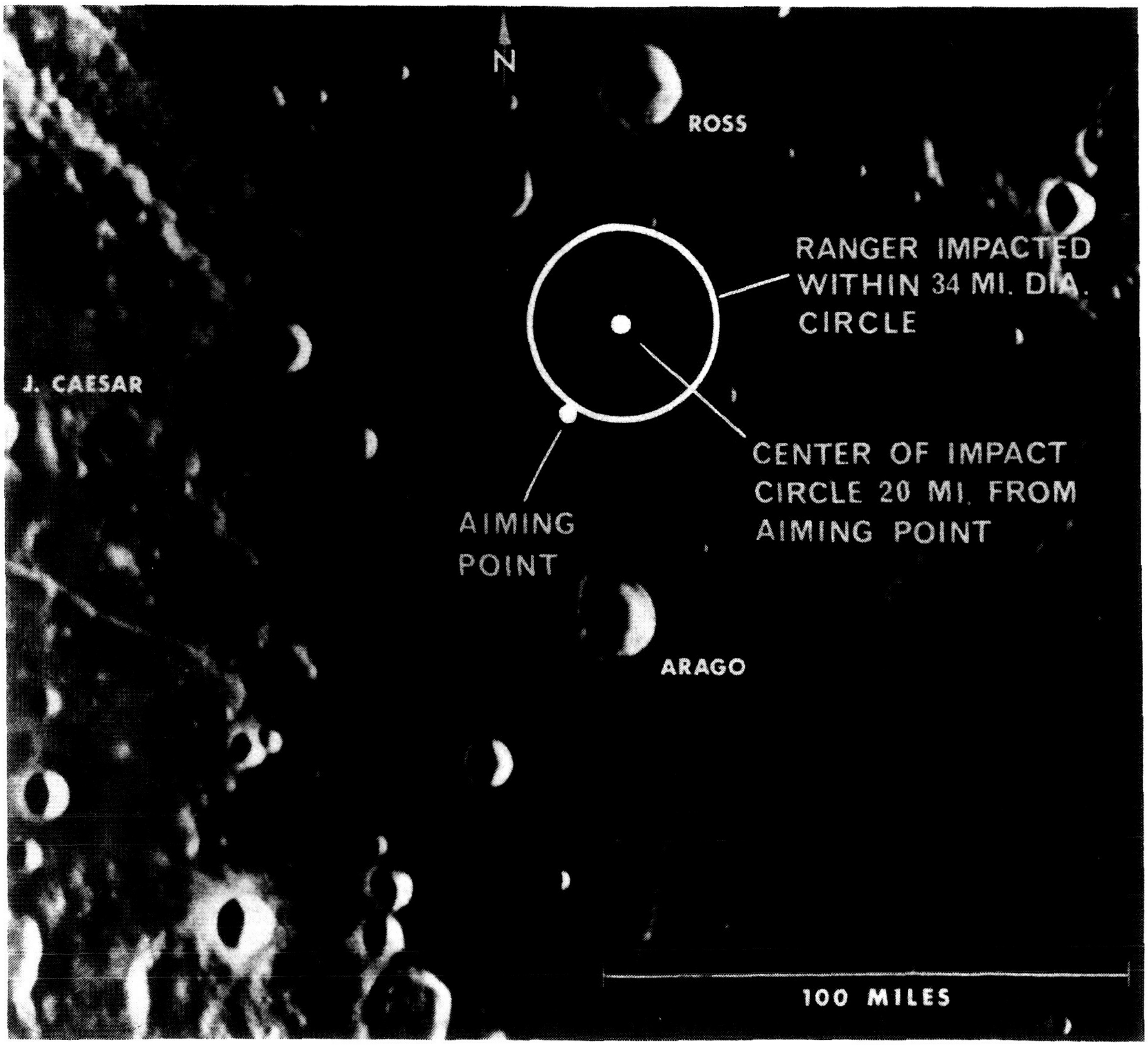

FIGURE 12.—Lunar landing area of Ranger, January 30, 1964.

N64-30338

EXPLORING THE SOLAR SYSTEM

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Exploring the solar system is a formidable topic to cover in one paper. Fortunately, Dr. Pickering has discussed the kind of exploration done by going directly to a planet; and Dr. Dessler has described the systematic studies which are underway on one planet's magnetosphere. So this paper can be confined to the kind of research undertaken to gain a better understanding of the Sun and its influence on the environment of the Earth and interplanetary space; it will also contain a brief review of the work underway in astronomy.

The following list shows some of our interests in space science:

- The space environment
- Sun-Earth relations
- Geodetic properties of the Earth
- Physical properties of the Moon
- Properties of the planets
- The fundamental physical nature of the universe
- The presence and behavior of life in space

We want to know and understand the space environment because of the interesting phenomena which take place there. We have to operate spacecraft in space and, therefore, have to know the environment. The area of Sun-Earth relations is a particularly important one. We need to know and understand the processes that take place on the Sun because the Sun controls the properties of the space environment. We are interested in the fundamental physical nature of the universe. Dr. Pickering already has discussed the work underway on the physical properties of the Moon and the planets. (NASA also has a program to study the presence and behavior of life in space; however, this can not be discussed in the brief time available.)

How do we go about exploring the solar system? How do we plan our program? In the geophysics and astronomy program, the study of solar physics is the unifying theme which ties much of our program together. Solar radiation and the solar wind determine the quiescent conditions in interplanetary space. Solar protons determine the radiation environment in space. The solar wind interacts with and distorts the magnetosphere. There are trapped particles in the magnetosphere which arise from solar flares. X-rays from solar flares affect the electron density in the ionosphere. The structure of the whole atmosphere fluctuates with an 11-year cycle of sunspot activity.

The Sun is the driving force behind much of the phenomena which we study in space; so, we must study the Sun, measure its radiation, and understand its temporal and spatial fluctuations before we can begin to interpret the data which NASA spacecraft collect on the magnetosphere, interplanetary space, atmosphere, and ionosphere.

This paper is concerned with (1) our solar physics program; (2) the measurements that we are making in interplanetary space; (3) briefly, the continuing studies of the magnetosphere; and (4) a brief description of the astronomy program. This will be a picture of the total NASA program in these areas, the rationale for it, some of our problems, and a look at the future program.

SOLAR PHYSICS

Figure 1 shows the sunspot cycle of the Sun—a plot of the number of sunspots as a function of time. This number reaches a maximum every 11 years, and we are presently at the minimum of the sunspot cycle. We do not know what the level of activity of

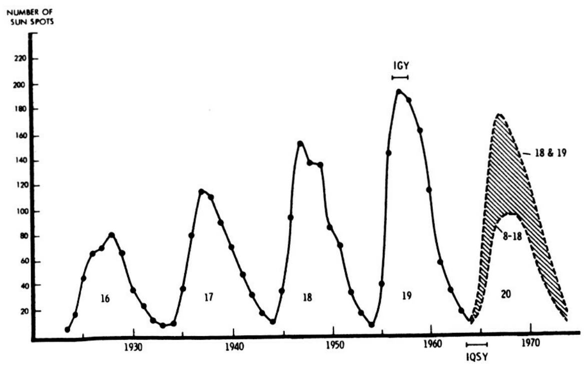

FIGURE 1.—Sunspot cycle.

the Sun will be during the next cycle. The upper curve shows the average of the last two cycles, the lower graph is an average of the last 10 solar cycles, and the next cycle should lie in the shaded region. Much of the thinking and planning within NASA must be phased to the solar cycle. We are presently preparing to fly spacecraft to study solar-terrestrial phenomena at solar minimum. NASA's flight program is established through 1966 and well into 1967; we have finished our planning for the spacecraft to be used during the transition from solar minimum to maximum. We are just beginning to work with the scientists and engineers to determine which projects and experiments need to be performed at the next solar maximum.

Why should we go to the expense and effort to place a telescope in orbit in order to study the Sun when there are numerous solar observatories scattered around the earth and scientists have been studying the Sun for over 400 years? The following are some of the several fundamental reasons why we must study the Sun in this way—with an observatory outside the atmosphere.

The curve on the bottom of figure 2 shows a rough plot of the solar intensity as a function of wavelength or color. The broad band in the middle shows the

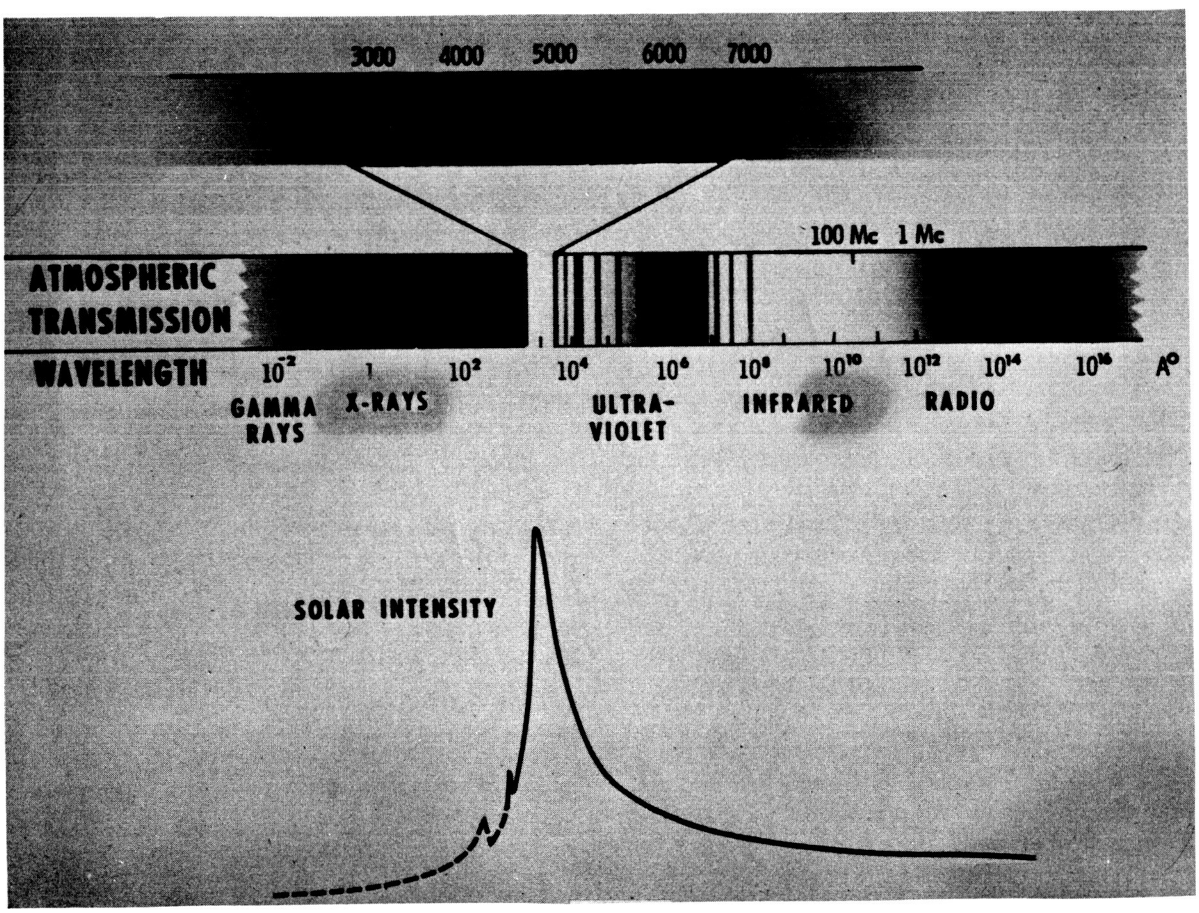

FIGURE 2.—Electromagnetic spectrum.

atmospheric transmission. The dark areas are the wavelengths which are absorbed by the atmosphere. The light regions are those wavelengths which can penetrate through the atmosphere to the surface of the Earth. There is a relatively narrow wavelength band centered around the peak in the solar intensity which is transmitted; this is the visible region of the spectrum, and at the top of the chart this is expanded. The regions of the spectrum which are absorbed by the atmosphere are much greater than those transmitted. The only way we can study the ultraviolet, gamma ray, and X-ray region of the solar spectrum is by placing our instruments above the atmosphere. In addition, these particular parts of the spectrum are highly variable. X-rays may change by many orders of magnitude during the solar flare. Certain regions of the ultraviolet vary with the existence of active regions on the Sun. Therefore, much of the information about the processes which take place on the Sun is contained in this portion of the solar spectrum. The ultraviolet light from the Sun produces the ionosphere, which is used for short-wave communication.

How do we observe the Sun? What does a solar observatory in space look like? Figure 3 depicts the Orbiting Solar Observatory (OSO). This is, and will continue to be our major project in the solar physics program. Originally we planned to have 8 OSO's. The first of these was launched in 1962. The second was at the launch pad early in April when a tragic explosion seriously damaged the spacecraft. At this time, we do not know exactly when the second OSO can be launched. The third will be ready for launch early in 1965. The remainder of these are scheduled to be launched at 9-month intervals.

The OSO consists of two parts: a sail or oriented panel, which points continuously at the Sun as long as the Sun is visible from the satellite; and a rotating section or electronic compartment, to provide stability. The major experiments are carried in a rectangular box pivoted in the sail. These experiments are pointed at the center of the Sun with an accuracy of about 1 minute of arc. Three gas bottles are placed on hinged booms to increase the moment of inertia about the spin axis. The first solar observatory was pointed at the center of the Sun continuously. The second solar observatory was planned to scan back and forth across the Sun to build up an image of the Sun in several wavelengths.

Figure 4 shows the kind of measurements that can be made on the Sun with a 1-minute pointing ac-

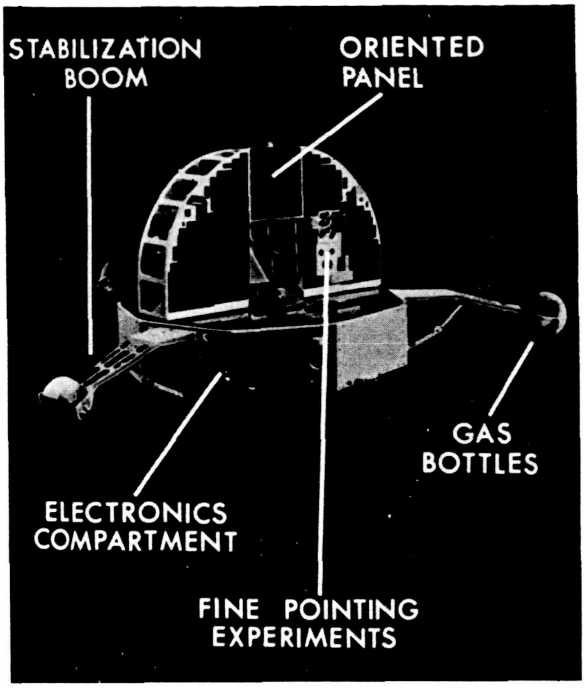

FIGURE 3.—The Orbiting Solar Observatory.

Gross weight	454 lb
Instrument weight	173 lb
Investigations	two-pointed
Power	16 watts
Stabilization	spin
Design life	6 months
Launch vehicle	Delta
Orbit:	
Apogee	370.30 miles
Perigee	343.85 miles
Inclination	33 deg
Status	launches in 1962 and 1964

curacy. The diameter of the Sun, as viewed from the vicinity of the Earth, is about 30 arc minutes; this is a typical picture of the Sun at solar maximum with several large sunspots visible. The middle picture is an enlargement of an active center on the Sun; the dark blotches on the left are sunspot groups. This picture was taken by a balloon-borne telescope; the square is 1-minute of arc on a side. Instruments on the present OSO will average the radiation coming from this total square. This pointing capability will enable us to study the radiation coming from a particular active center, but we cannot study the details of a particular sunspot. We need to resolve such

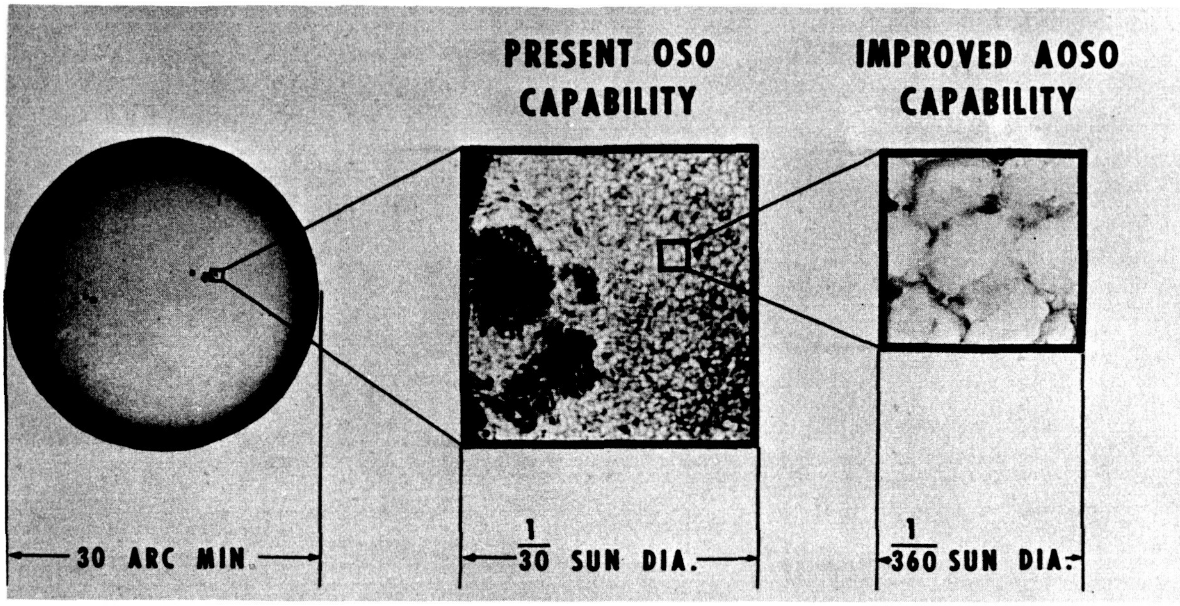

FIGURE 4.—Solar detail.

details. The picture on the right shows the resolution we expect from an Advanced Orbiting Solar Observatory, AOSO, which is being designed. The AOSO will have a pointing accuracy of 5 arc seconds.

To the right of figure 5 is an Advanced Orbiting Solar Observatory (AOSO) which will weigh about 900 pounds. The entire spacecraft will point continuously at the Sun; it will be launched into a polar orbit by a Thor-Agena. If Congress authorizes and appropriates the funds required, we will launch the first AOSO in 1968. We want AOSO to be operational during the next solar maximum.

Information on the radiation from the Sun will be provided by OSO and AOSO.

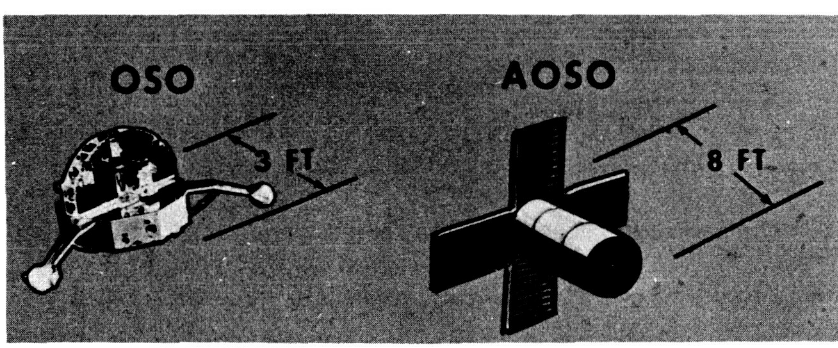

FIGURE 5.—Orbiting Solar Observatory (OSO) and Advanced Orbiting Solar Observatory (AOSO).

	OSO	*AOSO*
Weight, lb	500	1,000
Point accuracy, fraction of Sun dia.	$\frac{1}{30}$	$\frac{1}{360}$
Launch vehicle	Delta	Thor-Agena

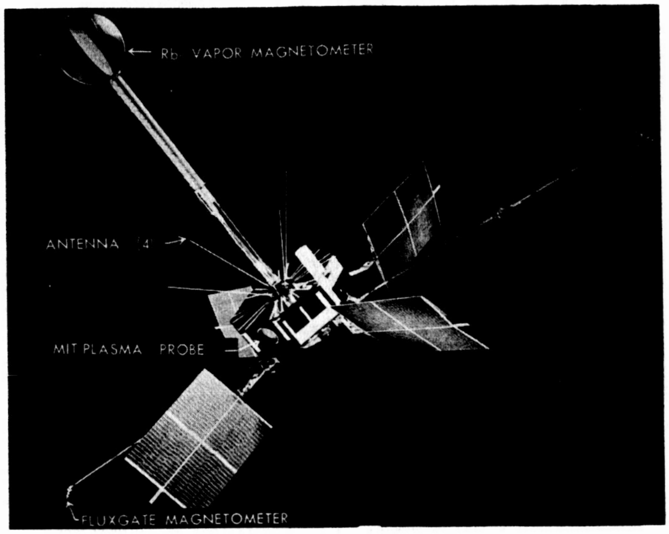

FIGURE 6.—The Interplanetary Monitoring Platform (IMP).

INTERPLANETARY PHYSICS

How does this radiation affect the environment? How do we study the environment? How do we use the data from OSO and OASO in these studies?

The answers to some of these questions are coming from our interplanetary physics program. There are three phenomena of interest in interplanetary space: the magnetic field, the plasma or "solar wind," and cosmic rays. All three are related and must be studied together; all three are strongly influenced by solar activity. The Sun continually emits clouds of electrons and protons which stream outward; this is the *solar wind*. The solar wind determines the shape of the magnetic field in space. The weak interplanetary magnetic field in turn, acting over large distances in space, determines the trajectories of cosmic rays. During major solar flares the Sun emits large numbers of high-energy protons, solar cosmic rays, which raise the radiation levels in space. The Interplanetary Monitoring Platform, or IMP as it is commonly known, was designed to measure these three parameters (fig. 6). It has two magnetometers, three plasma probes, and several energetic particle detectors. IMP is one of the flight projects in our program to study and to understand the environment in interplanetary space and in the Earth's magnetosphere. Seven IMP's were in the original program. The first was successfully launched in November and continues to operate. It was placed in a highly eccentric orbit; the maximum altitude is about 120,000 miles. The next two IMP's will have identical instrumentation and will be placed in similar highly eccentric orbits. The fourth and fifth will have different experiments and will be placed in eccentric orbits around the Moon. The remaining two will have the same trajectories as the first three but slightly different experiments.

Pioneer, IMP's partner in the exploration of interplanetary space is shown in figure 7. Pioneer has instrumentation similar to IMP; it will be fired into an escape trajectory from Earth. The combined measurements made by IMP and Pioneer will give us information on the configuration of the interplanetary field. It will help determine how a solar disturbance propagates, and it will begin to give information on the spatial configuration of solar proton events. Four Pioneers are scheduled. The first two will be placed on a trajectory which moves toward the Sun and will carry the Pioneer payload into about 0.8 or 0.9 AU. The payload and trajectories of the other two have not been decided. We will choose a payload late this spring and, on the basis of that payload, will decide on the trajectories. We might want to place them into a trajectory which will carry them out to perhaps 1.1 or 1.2 AU.

In addition to these two spacecraft, which are designed specifically to study interplanetary physics, the various planetary missions such as Mariner C and the Mars mission in 1966 will carry experiments in interplanetary physics.

We will need to use simultaneous measurements from OSO and ground observatories together with other ground-based measurements of the geomagnetic field, aurora, radio noise, and the ionosphere to under-

stand the complex interrelations between a solar flare, the propagation of the disturbance into the corona and interplanetary space, and the attendant effects on the magnetosphere and atmosphere of the Earth.

Figure 8 gives the two possible trajectories of Pioneer and the relative location of the Earth. If we fired two Pioneers simultaneously and kept an IMP in orbit around the Earth, we would be able to measure the azimuthal and radial gradients of the en-

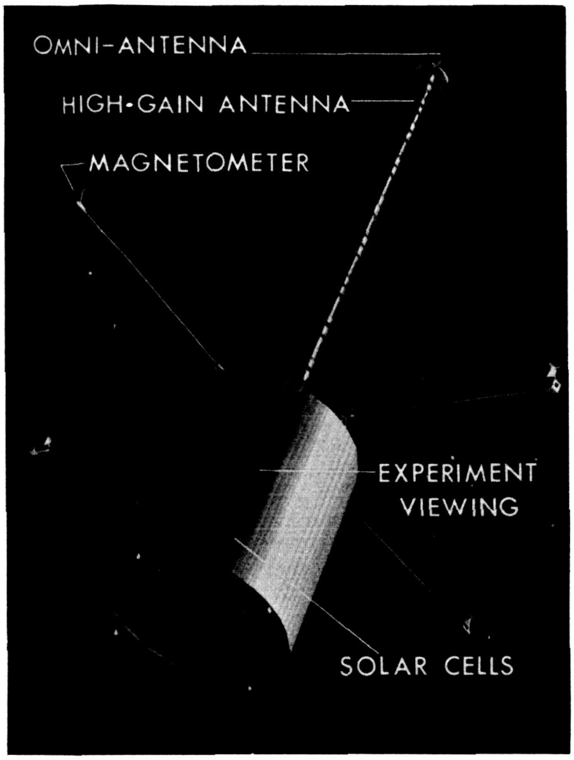

FIGURE 7.—Pioneer.

Gross weight	140 lb
Instrument weight	30 lb
Investigations	particles and fields
Power	50 watts
Stabilization	spin
Design life	6 months
Launch vehicle	thrust-augmented Delta
Mission	60 million miles from Earth 0.8 to 1.2 AU from Sun
Status	design completed first launch early in 1965

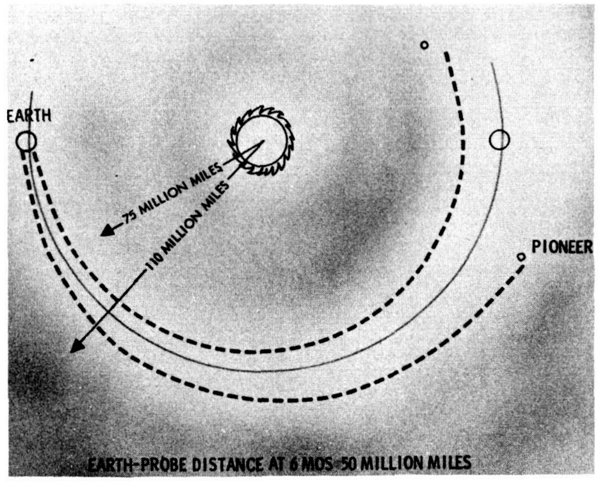

FIGURE 8.—Pioneer orbits.

vironment in interplanetary space. The seven IMP's and four Pioneers that we have scheduled will provide coverage from now to about 1967.

Where do we go from here? Will they provide all the data on interplanetary environment which we need? The answer is no. There are a number of other questions which we cannot answer with this coverage. What is the electron density and the magnetic configuration close to the Sun? How far from the Sun are the conditions in interplanetary space controlled by the Sun and its radiation? How far from the Sun do we have to go until we reach galactic space?

We think that complex configuration of plumes or streamers of the solar corona represent material flowing along the magnetic field. How can we begin to investigate this region of the solar corona? It requires a great deal of energy to send a spacecraft this close to the Sun, instruments will get very hot, and the radio noise from the Sun makes communication difficult.

Figure 9 depicts some possible trajectories of spacecraft launched from the Earth in such a way that they either move in close to the Sun or out from it. This chart shows the relative location of the Earth. By sending a spacecraft on a trajectory toward the Sun and by placing a radio transmitter aboard, we can begin to study the electron density in the corona by measuring the attenuation of the radio signal from the satellite as it passes behind the Sun.

We would like to begin an exploration of a new region of space with a simple spacecraft and a cheap

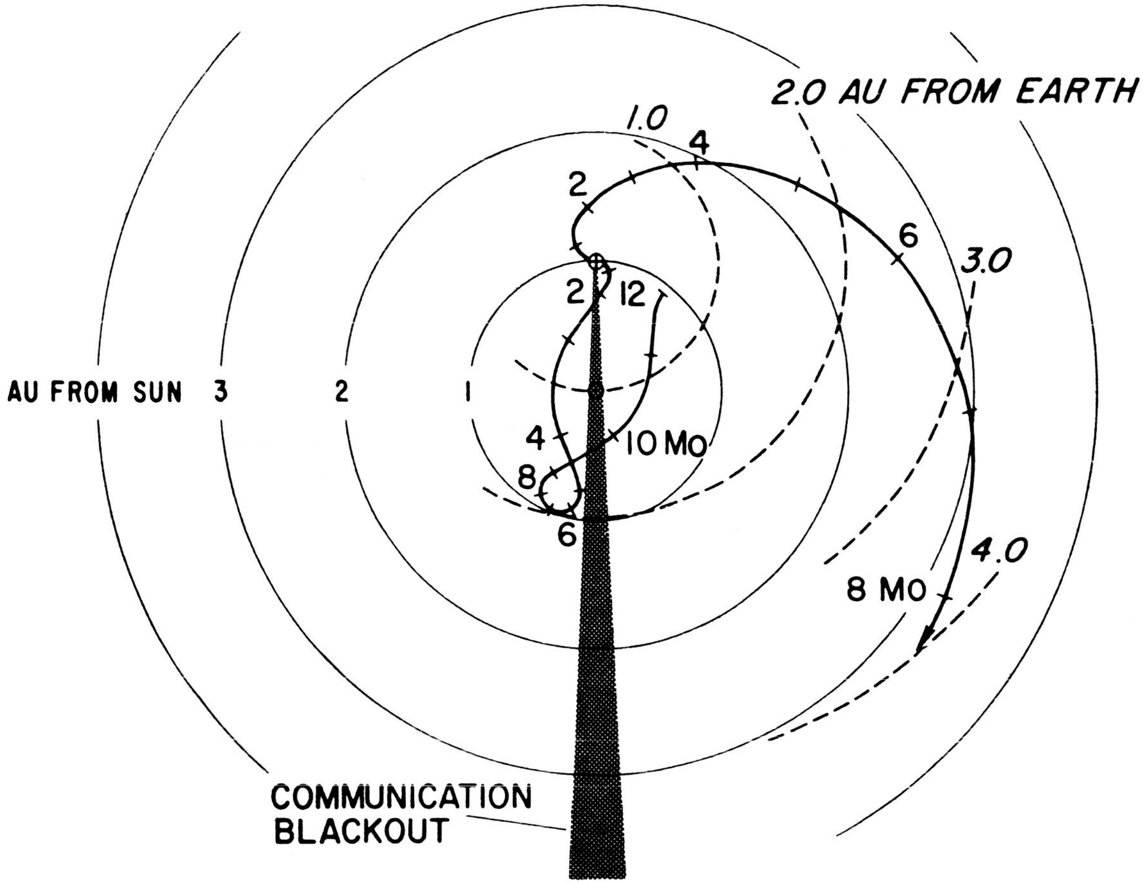

FIGURE 9.—Some possible trajectories of Earth-launched spacecraft.

launch vehicle. The first satellite which Van Allen used was a small satellite that weighed only a few pounds; yet it showed very interesting phenomena which we did not know existed. The data from that satellite were then used to design and build more complicated spacecraft to study the phenomena in detail. Perhaps we may do a similar job in the case of the solar corona. We have studies underway to use small multistage rockets to carry a small payload on a trajectory which passes behind the Sun to study the attenuation of the radio signal from that satellite.

PHYSICS OF THE MAGNETOSPHERE

NASA has a program to study the magnetosphere. Dr. Dessler already has discussed the scientific results which have been obtained over the past few years, and he has outlined some of the problems which remain to be solved. I will discuss the program which we have underway to solve these problems.

Figure 10 shows the behavior of the trajectory of a highly eccentric satellite such as IMP. The white dotted line roughly represents the magnetosphere, blown out into a *teardrop* shape by the solar wind. The solid line in each sketch shows the orbit of an eccentric satellite about the Earth; it remains fixed in inertial space. As the Earth moves around the Sun, the satellite on its trajectory covers various portions of the magnetosphere. This figure shows the relative orientation of the orbit of the satellite and the magnetosphere of the Earth as a function of the time of year (A, B, C, D).

NASA has had a systematic program underway for a number of years to explore the magnetosphere. Figure 11 is a chart looking down at the north pole of the Earth. The Sun is off to the left; the various cross-hatchings show the region of space which our satellites have explored. Since this figure was made, IMP has continued to work and has moved around

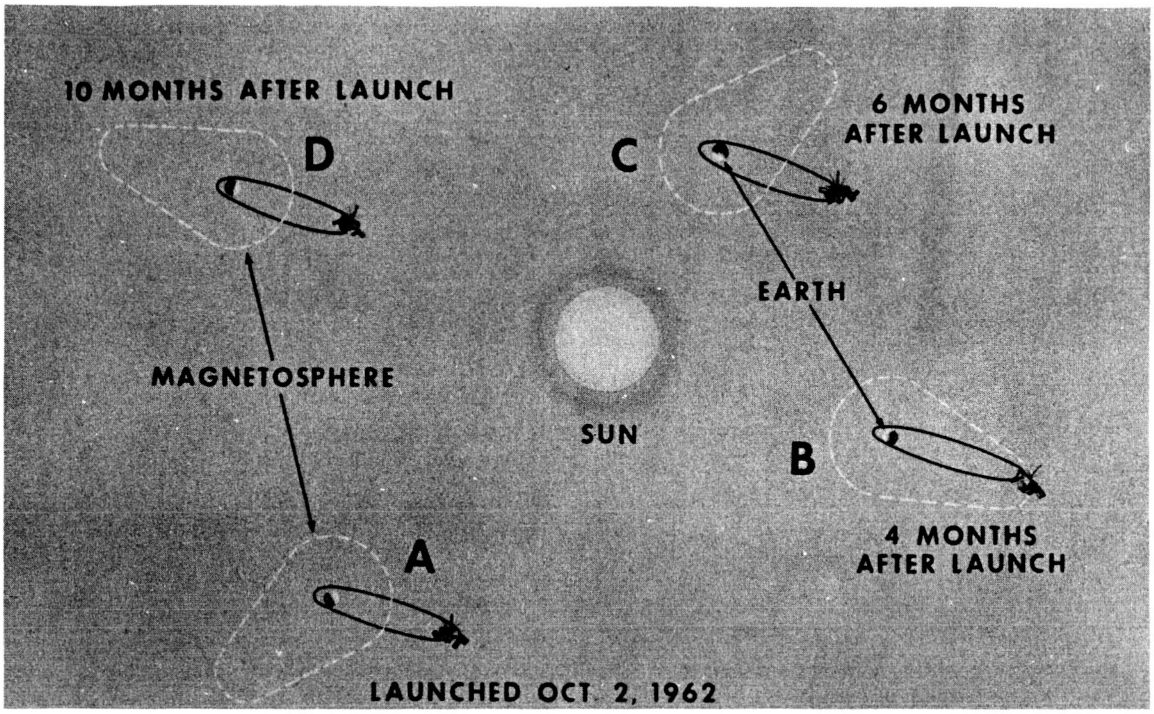

FIGURE 10.—Explorer XIV mission.

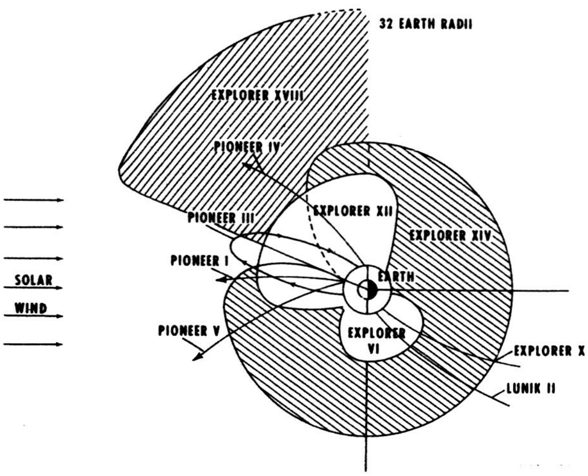

FIGURE 11.—Magnetospheric studies.

almost to the back of the magnetosphere. Explorer VI was limited by its lifetime and apogee to a relatively small region of space. Explorer XII covered a much larger region of space due to a higher apogee. Explorer XIV had a slightly higher apogee and lived considerably longer; it swept out almost the whole region of the magnetosphere. However, Explorer XIV spent very little time in interplanetary space. Explorer XVIII (IMP) was launched at a small angle to the Earth's Sunline. It has moved around to an angle of 90 degrees with respect to the Earth's Sunline. You will recall that five of the seven IMP's which are scheduled will be placed in highly eccentric orbits around the Earth and, as they sweep back and forth through the magnetosphere, they will give us information on the changes in the shape of the magnetosphere as a function of solar activity. However, the major effort to understand the magnetosphere in the future will be undertaken by the Orbiting Geophysical Observatory (OGO). The remaining problems of the magnetosphere are complex. We need to understand the origin of the trapped radiation and its lifetime; we need to understand how hydromagnetic waves propagate. All of these problems require simultaneous measurement of a large number of parameters and the transmission of a great deal of data back to the Earth.

Figure 12 shows OGO, which was designed for this purpose; it is a stabilized spacecraft weighing about 1,000 pounds and carrying 150 pounds of experiments. It is instrumented with magnetometers, with energetic particle measurements, with aurora and airglow experiments, and with experiments designed

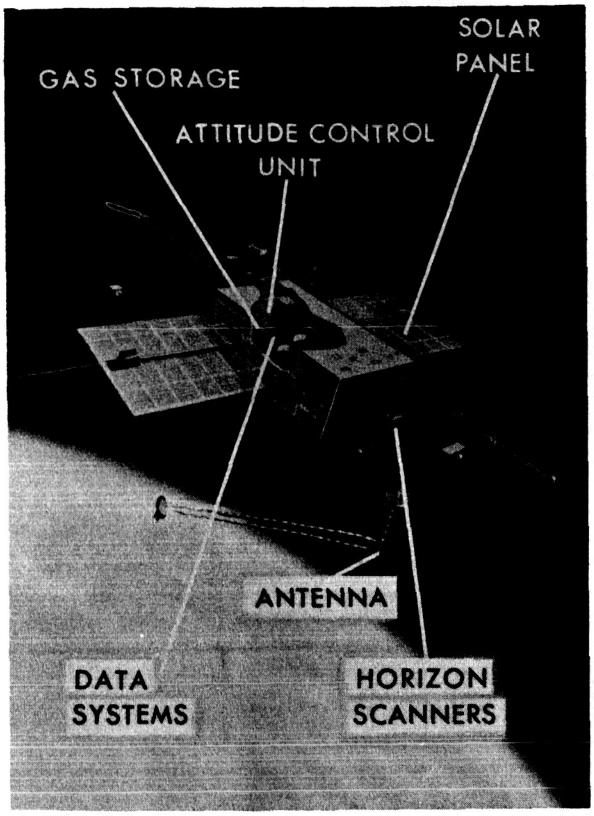

FIGURE 12.—The Orbiting Geophysical Observatory.

Gross weight	1,000 lb
Instrument weight	150 lb
Investigations	20 per spacecraft
Power	500 watts
Stabilization	active 3-axis
Design life	1 year
Launch vehicles	Atlas-Agena Thor-Agena

Orbits:
- Highly elliptical inclined orbit
- Near-circular polar orbit

Plan	first flight in 1964

to study the ionosphere. A major interdisciplinary attack will be made on all the problems of the magnetosphere and ionosphere. The data rate of OGO enables scientists to study hydromagnetic waves and to correlate magnetic fluctuations observed in the satellite with those observed on the ground.

The first OGO will be launched late this summer. There are two types of missions scheduled for OGO as shown in figure 13. EGO, the Eccentric Orbiting Geophysical Observatory, has a mission similar to Explorers XII, XIV, and IMP—a highly eccentric orbit going out to about 140,000 km. POGO, the Polar Orbiting Geophysical Observatory, will be placed in a low-altitude polar orbit to study the ionosphere and atmosphere.

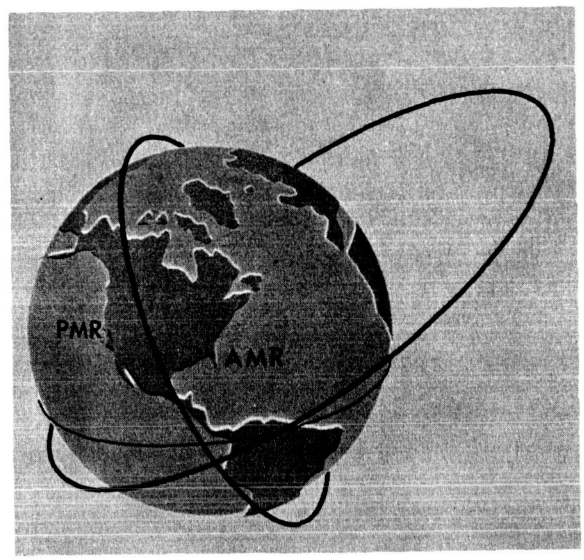

FIGURE 13.—The Orbiting Geophysical Observatory missions.

	OGO-A (EGO)	OGO-C (POGO)
Apogee, naut. miles	60,000	500
Perigee, naut. miles	140	150
Inclination, degrees	31	82-90

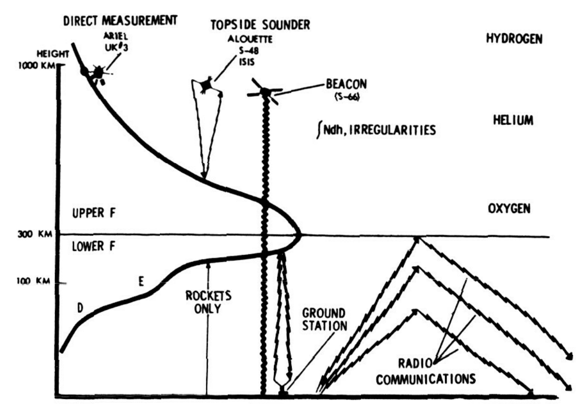

FIGURE 14.—Techniques for study of the ionosphere.

UPPER ATMOSPHERE AND IONOSPHERE

Closer to the Earth is the ionosphere and upper atmosphere program. Figure 14 shows the various techniques used to study the ionosphere. Prior to the advent of Earth satellites we studied the ionosphere by using a transmitter on the ground to send a signal vertically upward. Studies made this way showed that the electron density increased and apparently reached a maximum at about 300 km. However, it was not possible to use this technique to study the shape of the ionosphere above the maximum. Accordingly, one of the early satellites was designed to carry a *topside sounder* into orbit. This first satellite was Alouette, a Canadian satellite. It was highly successful and is still in operation.

However, Alouette has certain limitations. It continuously sweeps in frequency to build up the profile of the top side of the ionosphere. Consequently, it averages over fairly large regions of space. We have two satellites designed to study the spatial irregularities. The first of these is the fixed frequency topside sounder, which will be launched later this year. In this case, instead of transmitting a continuously changing frequency, we will fly a series of fixed frequencies. We will also fly what we call the Beacon satellite, a very simple satellite which will transmit a number of frequencies to be monitored by ground stations. By studying the relative attenuation and phases of these signals we will be able to measure the total number of electrons between the satellite and receiving station. We have already planned our fu-

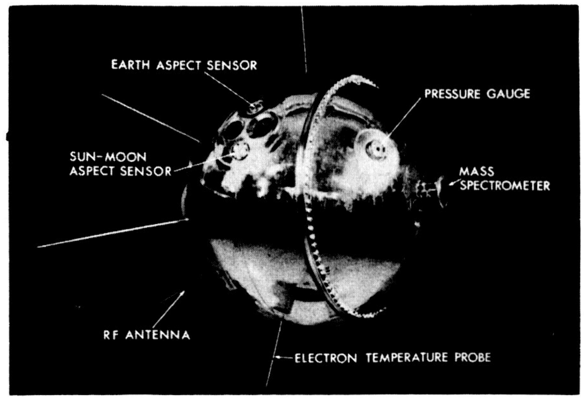

FIGURE 15.—The Atmospheric Structure Satellite.

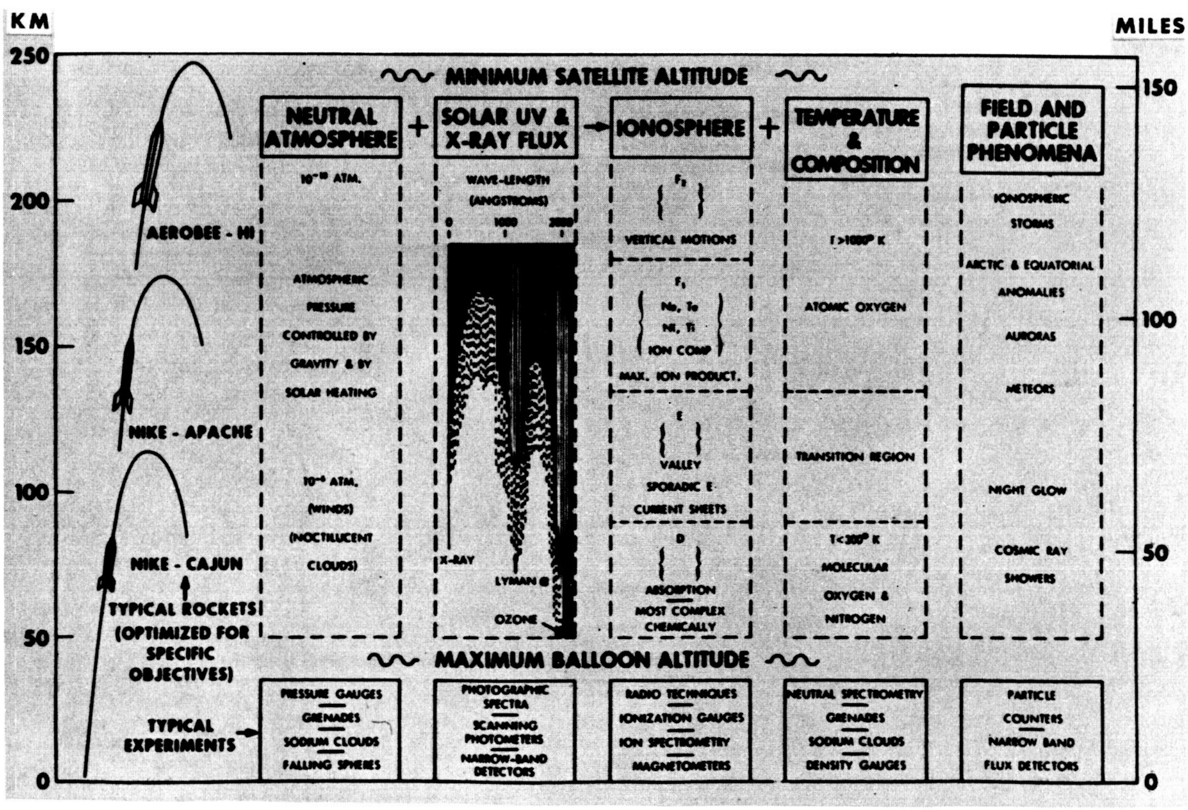

FIGURE 16.—Basic research requiring low-altitude sounding rockets.

ture work in the ionosphere over the next 4 years. We plan to continue a cooperative program with the Canadians. They will build the satellites, we will furnish the boosters, and both countries will share the data from the satellites. The name of this program is Isis (International Satellite for Ionospheric Studies). Four launches are scheduled in the Isis program. These four shots include a repeat of Alouette and three launches of a new satellite.

The various satellites shown are all different; they each have different missions and have certain peculiarities. Figure 15 depicts the Atmospheric Structure Satellite (S–6a) which can be regarded as a vacuum chamber turned inside out. It is quite a problem to obtain a high vacuum on Earth; the vacuum in space at satellite altitude is comparable to the very highest conditions obtainable on Earth. Therefore, in order to study the composition and structure of the atmosphere at that altitude, we must prevent contamination by the satellite of the surrounding region of space. The S–6a consists of a stainless steel, vacuum-tight shell with all the instruments, the battery, and telemetry transmitter sealed inside, and with only the mass spectrometers and other detectors exposed to the ambient conditions. The first Atmospheric Structure Satellite was successfully flown early this year. The second Atmospheric Structure Satellite will be flown early in 1965. The first satellite was placed in a low-inclination orbit, and the second will be placed in a polar orbit.

One of the major questions, from both a scientific standpoint and the standpoint of knowing and understanding the behavior of a satellite in orbit, is the determination of the atmospheric drag. Early measurements have shown that the drag on a satellite varied with solar activity, and it appears that the entire atmosphere expands and contracts over the 11-year solar cycle. To study this phenomenon, we use large lightweight balloons. Two 12-foot spheres have been launched: one in a low-inclination orbit, and another in a polar orbit. The first of these recently reentered the atmosphere after giving measurements for over 2 years. We plan to launch two more 12-foot balloons later this year to study atmospheric density. These will be launched together with two Injun Explorers to study the effect of precipitation of trapped radiation on the atmosphere. We will track the 12-foot balloons to determine the density of the atmosphere. The Injun satellite will measure the flux of the trapped radiation.

Most of our work on the structure of the atmosphere must be done with sounding rockets. Balloons can reach an altitutde of only about 40 km. Satellites, on the other hand, can operate only about 250 km; if they come much below this altitude, the drag is such that they will reenter the atmosphere after only a few days. Therefore, to make direct measurements in this region, it is necessary to use sounding rockets.

Figure 16 illustrates some of the basic research which we have underway with low-altitude sounding rockets. We use sounding rockets to study the neutral atmosphere, to measure the electron density directly, to study the temperature and composition, and for certain energetic particles for the astronomy program. So far, we have discussed the interplanetary space and the immediate environment of the Earth.

ASTRONOMY

Astronomy may be one of the most important programs we have. Why should we go through the

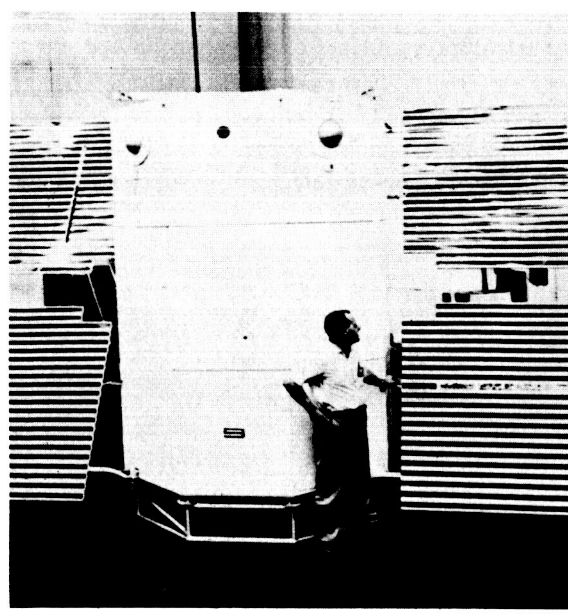

FIGURE 17.—The Orbiting Astronomical Observatory.

Four 12-inch Smithsonian telescopes to map entire sky in ultraviolet

Four 8-inch and one 16-inch Wisconsin telescopes to study bright stars and nebulae

3-foot Goddard telescope studies 5,000 stars and nebulae

32-inch Princeton telescope studies interstellar matter

Ultimate pointing accuracy of 1/36,000 of 1 deg

3,600 lb in 500-mile circular orbit

trouble and expense of placing a large observatory in orbit when we have such magnificent facilities as the 200-inch telescope at Mt. Palomar? The reason is much the same as the reason for studying the Sun. There are a large number of stars which radiate the bulk of their energy in either the ultraviolet or the infrared portion of the spectrum. To study stars at all stages in their evolution, we must be able to measure their light in both the infrared and ultraviolet. In the very early processes, when a star is forming, it is cool and radiates in the infrared. Later in their evolution stars are hot and radiate most of their light in the ultraviolet. We think that these stars in the ultraviolet and infrared light will provide fundamental data which will help in understanding stellar processes and the nature and history of the universe.

The OAO, shown in Figure 17, is easily the most complex and most expensive scientific spacecraft which we have under development. It will weigh 3,600 pounds and is designed to point experiments to an accuracy of a 10th of a second of arc. At present three spacecraft and four separate sets of experiments are being built. The first OAO, which is scheduled for launch in late 1965, will carry two sets of experiments. One experiment, supplied by the Smithsonian Astrophysical Observatory, consists of four 12-inch telescopes to map the sky in ultraviolet light. A second experiment, from the University of Wisconsin, consists of four 8-inch and one 10-inch telescopes to study bright stars and nebulae. The second OAO is planned to carry a 3-foot telescope, provided by the Goddard Space Flight Center, to be used to study some 5,000 stars and nebulae. The third OAO will carry a 32-inch Princeton University telescope to study interstellar matter.

SUMMARY

In summary:

1. NASA has a vigorous program to explore the solar system. This is a program which requires simultaneous measurement of the Sun and its radiation together with measurements at widely separated points in interplanetary space, in the magnetosphere, and in the ionosphere. This program will have to be augmented during the period of next solar maximum, 1967–72.

2. There is an opportunity in this program for fundamental discovery with new insights into stellar processes and stellar evolution.

3. We hope to proceed from simple missions with simple spacecraft to more complex and difficult missions.

N64-30339

DISCOVERIES FROM SPACE EXPLORATION

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Space science is the collection of problems in science to which space vehicles can make some specific contribution not achievable by ground-based experiments. At the present time this field includes broad segments of the traditional disciplines of the earth sciences, physics, and astronomy. In later years the biological sciences will join this group in an important role, as explorations of the Moon and planets provide opportunities for studying the conditions under which physical life may have developed. Some highlights of recent space research will be reviewed here.

GEODESY

Important results have been achieved in determining the internal structure of our own planet with the aid of near-Earth satellites. A satellite's orbit is determined by the distribution of mass within the Earth. If the Earth were a perfect sphere, under the attraction of the mass point at the Earth's center of gravity, the satellite would move in an ellipse whose plane would keep a constant orientation in space.

Actually, the plane of a satellite's orbit rotates slowly in space because of the additional force of attraction exerted by the equatorial bulge. Studies of the orbital rotation rates of a number of satellites have yielded a very precise value for the height of the equatorial bulge. These indicate a discrepancy between the observed value of the flattening and the value that should exist on the assumption of hydrostatic equilibrium. Hence the interior of the Earth is not in hydrostatic equilibrium; the Earth must have a mechanical strength within its interior or some other cause for departure from static equilibrium which is sufficient to maintain its shape in spite of the stresses applied to the mantle by the excess equatorial bulge.

There are other departures of the geoid from the shape of hydrostatic equilibrium, in addition to the discrepancy in the flattening. These departures, which have been determined primarily from the analysis of the Vanguard I orbit, include a pear-shaped component, or third harmonic, in the expansion of the gravitational field.

The departures from the figure of hydrostatic equilibrium are of very great significance because they represent variations in the force of gravity, and these depend on the entire distribution of mass within the planet; they are therefore more significant for the gross structure of the planet than the simple topographical variations, such as mountains, which represent the distribution of the mass at the surface only.

Detailed analysis of these gravitational variations yields a figure of the Earth in which there is a positive anomaly, or a lump, in the region of the western Pacific near Indonesia and the Philippines; a depression, or negative anomaly, in the Indian Ocean; and a large negative anomaly, or hole, in the Antarctic (fig. 1).

Although these depressions and elevations are relatively minute, they are exceedingly significant because

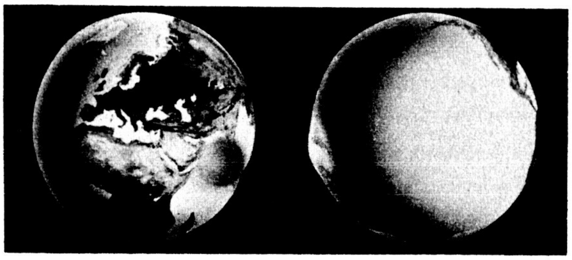

FIGURE 1.—Shape of Earth.

they represent variations in the force of gravity, or the amount of matter per square centimeter, in the regions in question. For example, the depression in the Indian Ocean is only 60 meters deep, but it signifies that the force of gravity there is so weak that the waters of the sea are not drawn together to the depth that they would be if the whole Earth were subject to a uniform gravitational force.

These anomalies are correlated with the rate at which heat flows through the body of the Earth to the surface. The correlation is such that where the geoid is anomalously high, the heatflow is anomalously low. On the average, the flow of heat outward through the crust of the earth is 60 ergs/cm^2-sec. In the depression of the geoid near India, the flow of heat is substantially higher, 80 ergs/cm^2-sec. At the elevation of the geoid in the western Pacific, the flow of heat is substantially lower, about 40 ergs/cm^2-sec.

This kind of correlation would be expected if there is a mass transport, or convection of matter, from the deep interior of the Earth to the surface in these regions. If there were an upward motion through the interior of the Earth, which carried relatively warm material from below to the surface, this upward-moving column would have a lower density than its surroundings, and therefore the mass per square centimeter in the column, and the gravitational force on the surface of the Earth about it, would be lower than on the average. At the same time, the heat transported upward by the warm column would add to the normal release of radioactive heat throughout the mantle and crust; thus, above that same upward-moving column there would be an exceptionally large rate of heat flow through the surface.

The converse would hold for a descending column, which would carry a relatively dense and therefore relatively cold material from the surface layer to the interior of the Earth. Above the cold and dense column the gravitational force would be relatively great, and a bump would appear in the sea level there. That is presumably the cause of the elevation in the western Pacific.

METEOROLOGY

In geocentric order, the next major area of investigation in space science concerns the atmosphere and the control exerted over it by the Sun. This field of research includes questions related to the circulation of the winds in the lower atmosphere and to the vertical structure of the atmosphere at higher altitudes.

Regarding atmospheric circulation, eight Tiros satellites have been launched in the past 4 years, all carrying vidicon cameras for the global study of the cloud cover; Tiros II, III, IV, and VII carried in addition a set of infrared detectors for the measurement of the intensity of infrared radiation emitted from the atmosphere.

The cloud-cover photographs have already yielded results of great interest when correlated with ground observations, and they have the promise of leading to a substantial improvement in weather forecasting by providing global and nearly continuous coverage of regions of weather activity. The matter of global coverage is critically important, because the success of weather forecasting has been found to increase rapidly with the size of the region covered by the observations; yet at the present time large parts of the globe are very poorly covered, and constitute regions in which weather activity can develop and grow without detection before moving out into the inhabited areas. The sparsely covered territories include the polar regions, the major deserts, and the southern oceans. Satellite coverage will greatly strengthen the hand of the meteorologist by filling in these blank portions of the global weather map and may be expected to have important consequences for the economies of this country and the world.

The measurement of infrared radiation is less important than cloud-cover photography for the immediate objectives of weather forecasting, but it should have greater importance for the basic objectives of long-range forecasting and the understanding of the causes of weather.

Although the Sun is the original source of energy, most of the solar radiation is in the visible band of wavelengths which passes freely through the atmosphere. This visible radiation reaches the surface of the Earth where it is absorbed and heats the ground to a temperature in the neighborhood of 235° K. The ground emits radiation corresponding to this temperature. For a glowing body at a temperature of 235° K, most of the energy is radiated at wavelengths in the far infrared. This infrared radiation is strongly absorbed by several constituents of the atmosphere, including water, carbon dioxide, and ozone. The absorption of infrared from the ground by these molecules heats the lower atmosphere, which reradiates the absorbed energy, partly upward to outer space and partly downward to provide additional heating of the surface. (The additional heating of

the surface by the return of infrared from the atmosphere is referred to as the "greenhouse effect." On the Earth it is sufficient to raise the temperature by about 55° K, so that the average temperature of the surface of our planet becomes 290° K.)

Local variations in the amount of water vapor, and in other circumstances which control the penetration of visible light and the reradiation of infrared, lead to regional variations in the temperature and pressure of the atmosphere, which in turn provide the driving force for large-scale weather activity (fig. 2 and 3).

If a good spectral distribution of infrared intensities is available, we can obtain from it the temperature distribution in the lower atmsophere, as well as the global variations in the total transfer of energy. These are vital data for the atmospheric physicist seeking the causes of weather.

In addition, the cloud-cover information obtained from satellites can be used to estimate the amount of incoming visible radiation which actually reaches the ground. The difference between the incoming visible radiation and the outgoing terrestrial radiation in the infrared region makes up the energy balance of the Earth and the atmosphere, which is the fundamental datum for long-range prediction.

These are the general circumstances which underlie the development of weather activity. The details of the process involve the following considerations. The intensity of infrared radiation emitted from the ground is determined by the temperature of the ground: the higher the ground temperature, the stronger the infrared radiation. The absorption of this infrared in the atmosphere is largely determined by the water vapor present, this being the principal absorbing constituent. It is also affected by any clouds which may be present since liquid water droplets also absorb infrared strongly. Thus, the most important factors which control the outgoing infrared radiation are, in order: the ground temperature, the amount of water vapor in the atmosphere, and the extent and height of the clouds.

It is seen that the distribution of cloudiness plays an important role in the determination of both the inflow and the outflow of energy through the Earth's atmosphere. Thus far the distributions of clouds—amount, types, and approximate heights—have all been taken from ground-based observations. Satellite observations by television cameras enable us to obtain extensive cloud-cover data on a global scale in a relatively short period of time.

Albert Arking of the Goddard Institute for Space Studies has compared the Tiros results with a climatological mean cloudiness compiled from ground observations by K. Telegadas and J. London (1954) for the Northern Hemisphere. The broad features are in agreement, although there are small numerical disagreements at some latitudes. The most noticeable disagreement, which occurs around 20° S. latitude, is probably due to the incorrectness of the assumption that cloudiness is the same during southern winters as during northern winters.

These results are preliminary, but this approach seems to be promising, and it is hoped that the temporal and geographical variations in the distribution of energy balance will now be available through the use of both outgoing and incoming radiation

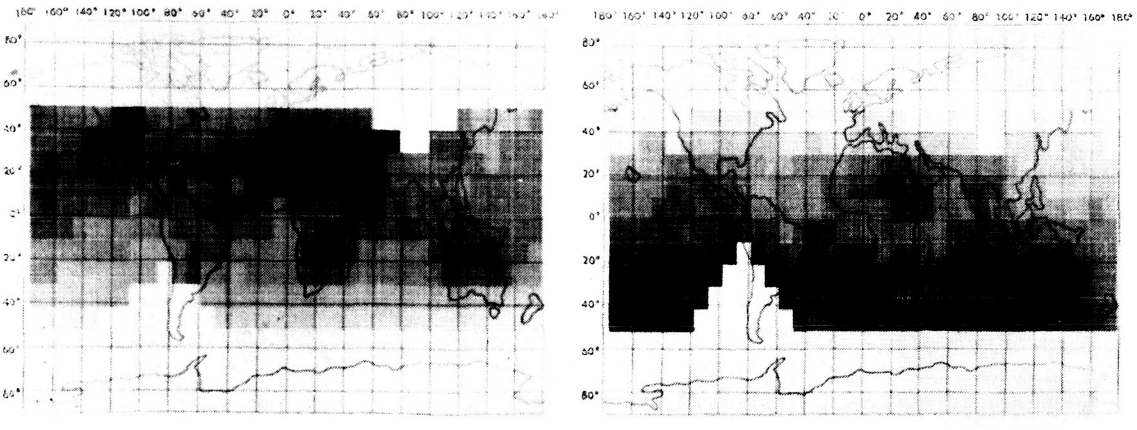

FIGURE 2.—Energy balance, summer (left) and winter (right) of 1961. From Tiros III

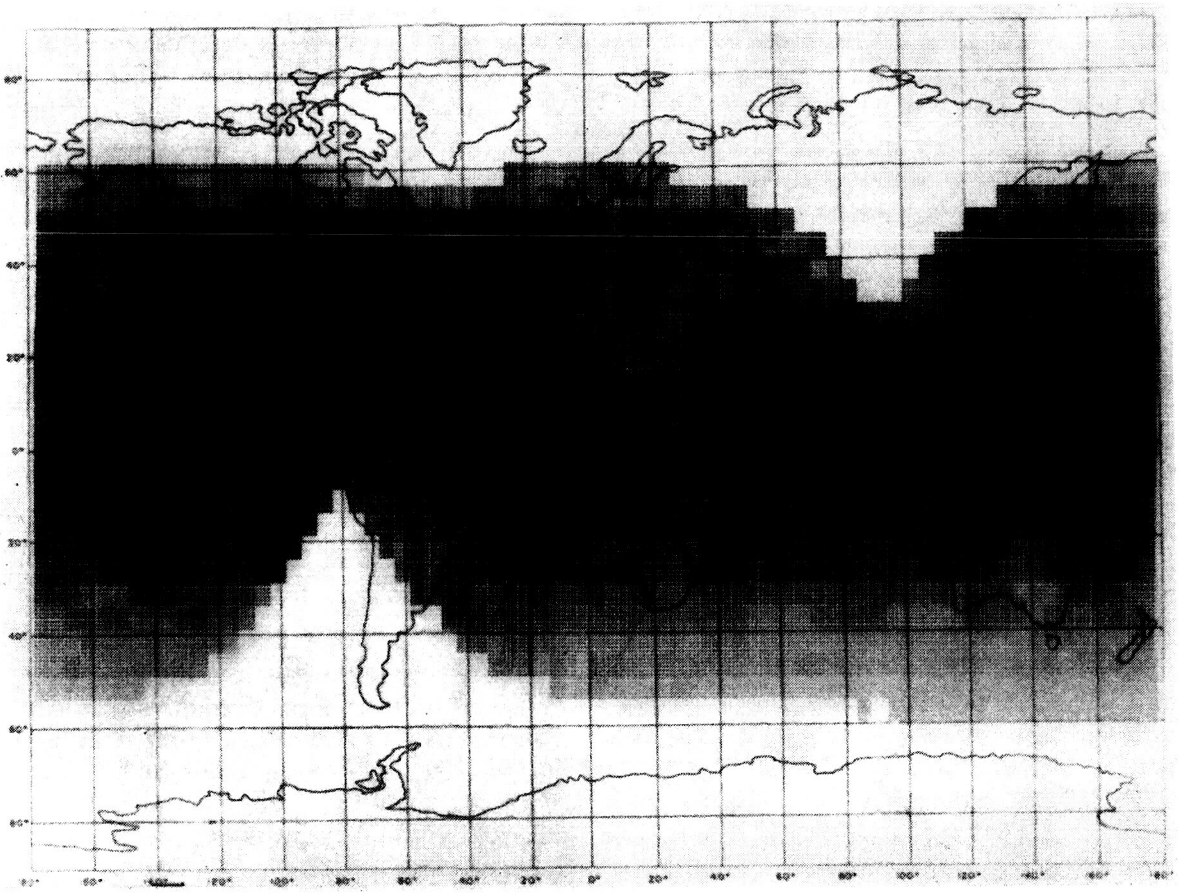

FIGURE 3.—Energy balance, spring of 1962. From Tiros IV.

obtained from satellites. In turn, this method may provide a better understanding of the role played by the energy balance of the atmosphere for long-range weather forecasting.

THE UPPER ATMOSPHERE

The physical processes which control the upper atmosphere are determined largely by the absorption of solar ultraviolet radiation by the atoms and molecules existing at great heights. Although the ultraviolet component of the solar radiation is only a small fraction of the total solar energy flux, the absorption of cross sections in the far ultraviolet are so large that these wavelengths are effectively removed from the incident spectrum by the time the incident flux has penetrated to a height of 100 km. The ultraviolet radiation is the principal source of heating of the thin upper air and the major determining factor in its structure.

At lower altitudes the air is composed of oxygen and nitrogen, and we can measure the proportions of these rather accurately. At the highest altitudes these gases have partially settled out of the air through diffusion. The lighter gases dominate the composition of the air at sufficiently high altitudes. Of these gases hydrogen is the lightest, and for this reason it was once believed to be the dominant constituent of the air above the oxygen-nitrogen layer. The hydrogen atmosphere was thought to emerge at an altitude of about 1,200 km. However, in July 1961, Marcel Nicolet of Belgium suggested on the basis of an initial examination of the density data of Echo II that between the oxygen-nitrogen atmsophere and the hydrogen atmosphere there should lie a layer of helium. The existence of the helium layer was confirmed experimentally at approximately the same time (fig. 4).

Our knowledge of atmospheric properties at altitudes of about 250 km is dependent on the measure-

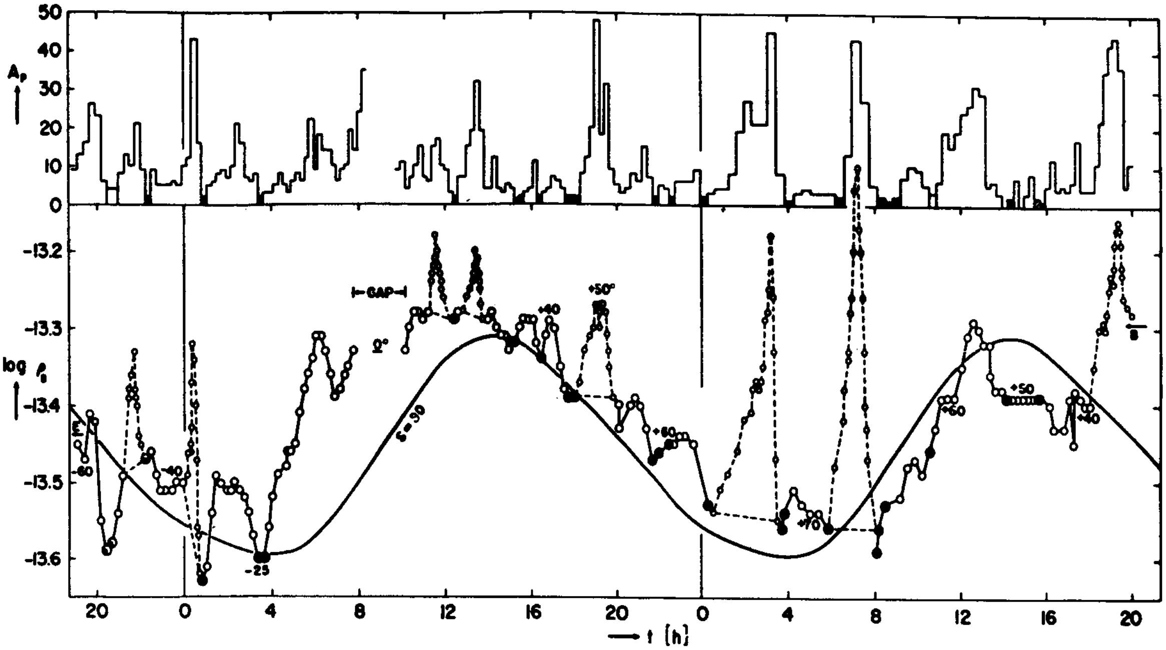

FIGURE 4.—Satellite drag.

ments of the atmospheric drag acting on satellites. The period of revolution of a satellite decreases steadily at a rate proportional to the drag force exerted by the atmosphere; and the coefficient of the observed rate of change of period therefore gives the value of the air density suitably averaged around the orbit.

The detailed study of satellite drag has in fact been a very valuable source of information on atmospheric properties. The most interesting result of investigations carried on by L. G. Jacchia of the Smithsonian Astrophysical Observatory was the discovery that the upper atmosphere is extremely responsive to solar control, undergoing excursions in density which were lately found to be as much as a factor of 100, and variations in temperature of hundreds of degrees, according the level of solar activity.

The significance of this correlation can be understood as follows: During the maximum of the sunspot cycle, the surface of the Sun is the scene of great activity, marked by sunspots and by hot, dense regions with temperatures of some millions of degrees, which are located in the solar corona above the sunspot areas. When such an active region faces the Earth in the course of the Sun's rotation, extreme ultraviolet radiation emitted from these active regions is absorbed in the upper atmosphere. The precise correlation between solar activity and density, discovered initially by Jacchia of the Smithsonian Astrophysical Observatory and W. Priester of the Institute for Space Studies, suggests that the amount of energy transferred to the Earth is sufficient to heat the atmosphere appreciably, causing an upward expansion and a large increase in the density of the exceedingly thin air at high altitudes. This discovery provided the first direct evidence regarding the effects of solar surface activity on fundamental atmospheric properties.

The continuing analysis of the correlation has given us a rather full picture of the degree of solar control over the upper atmosphere. It indicates that the atmosphere is appreciably heated by the ultraviolet emitted at times of general solar surface activity; analysis has also indicated that the atmosphere is further heated by interaction of the Earth with the solar plasma clouds, which are emitted from the Sun following solar surface eruptions. The arrival of the clouds of solar plasma at the Earth is signified by the onset of geomagnetic disturbances or "magnetic storms" (fig. 5). It is found that increases in the temperature of the atmosphere occur at just the time that the magnetic storms and, hence, the solar particles commence. Thus it appears that both ultraviolet radiation and corpuscular streams constitute sources of energy for the upper atmosphere. The question of

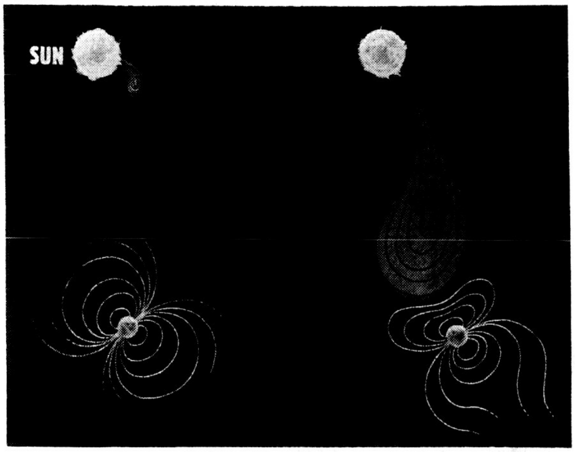

FIGURE 5.—Solar plasma cloud.

the energy sources for the upper atmosphere is the most important single problem for upper-atmosphere physics at this time and the continuing investigation of this matter, and in particular of the roles played by particle and radiation sources respectively, will be one of the main areas of experimental and theoretical effort in the next several years.

THE MAGNETOSPHERE

The evidence that has been cited suggests that corpuscular streams from the Sun transfer appreciable amounts of energy to the atmosphere. The question arises, How does the transfer of energy in the atmosphere occur?

The general answer seems to be connected with the properties of the outermost layer of the atmosphere. The density of the upper air merges into the density of the interplanetary gas at an altitude of about 100,000 km, marking the boundary of the atmosphere. Early in 1958, however, J. A. Van Allen of the State University of Iowa discovered, by analysis of Geiger counter data from Explorer I, that there was an additional layer of energetic charged particles in the upper atmosphere. These charged particles are trapped in the atmosphere by the Earth's magnetic field. The atmospheric layer which they constitute is called the magnetosphere, since it is the region dominated by the geomagnetic field.

During the last few years, three important developments have substantially changed our earlier impressions about the character of the magnetically trapped particles and their geophysical effects.

First, B. O'Brien, also of the State University of Iowa, using measurements from the Injun I satellite, discovered that the flux of charged particles coming down from the trapped region was so large that, if this flux consisted of previously trapped particles which had just been dislodged by solar disturbances, it would drain the whole magnetosphere in about an hour. He also found that when a solar disturbance occurred, both the flux of untrapped descending particles and the number of trapped particles increased. Thus, he concluded that the leakage of trapped particles from the Van Allen belts cannot be the principal source of the electrons which pass down through the atmosphere. He decided that while a few charged particles are trapped during or after a solar disturbance, most pass into the atmosphere directly without spending an appreciable amount of time in the trapped region. Apparently, the charged particles which are observed in auroral displays and other atmospheric phenomena are those which come directly down the lines of force into the atmosphere.

Secondly, a large population of low-energy protons, having a range from 100 Kev to several Mev, was discovered by A. H. Davis and J. M. Williamson of the Goddard Space Flight Center. The concentration of these protons peaks at 3.5 Earth radii. At that point their density is about 1 per cubic centimeter.

This value of the trapped-proton density has interesting implications. As a result of the magnetic-field gradient and curvature effects, the trapped protons drift westward in the magnetic field, with an associated electric current that produces magnetic effects. These have been calculated by S. Akasofu of the University of Alaska and S. Chapman of the University of Colorado and, in an unpublished work, by R. A. Hoffman of the Goddard Space Flight Center. They find that the changes in the intensities of these trapped protons produce magnetic perturbations large enough to explain most magnetic storms observed on the Earth, and also the very large perturbations of the geomagnetic field in space, in the neighborhood of the proton belt. The relation between the trapped-proton drift current and the geomagnetic storms was suggested by S. F. Singer of the University of Maryland in 1956.

The third development was the discovery of a substantial flux of electrons with very high energies, in the neighborhood of 1 million volts, at a distance of 3 or 4 Earth radii, presumably produced by beta decay

of albedo neutrons resulting from cosmic-ray interactions in the atmosphere. These electrons penetrate the Geiger counters with high efficiency, and when allowance is made for their presence, the earlier estimate of the total flux of electrons is reduced from Van Allen's value of 10^{10} to the latest value of 10^8.

THE MAGNETOPAUSE

The connection between the magnetosphere and the transfer of corpuscular energy to the atmosphere is probably to be found in the properties of the magnetosphere near the magnetopause, a region which separates the interplanetary medium from the region around the Earth in which the geomagnetic field is dominant. Its sharply defined surface marks the termination of both the trapped-particle region and the geomagnetic field. Satellite measurements of the geomagnetic field by L. J. Cahill of NASA Headquarters in Washington show that the magnetopause has a thickness on the order of 100 km and occurs at a distance of 8 to 10 Earth radii on the sunlit side of the Earth (fig. 6).

Within the region of the geomagnetic field there are no substantial particle fluxes other than those of the magnetically trapped particles. Outside the geomagnetic field, experiments on Explorer X and Mariner II have shown that a substantial number of particles move outward in a radial direction from the Sun at velocities varying from 300 to 600 km/sec and at an average flux of $10^8/cm^2/sec$. Mariner II measured a higher kinetic energy in the directed solar plasma streams than in the random particle motions in the stream. The solar plasma cloud drags the lines of solar magnetic field with it, and its bulk motion is not affected by the presence of the field (fig. 7).

These results, taken together, indicate that the Sun is the source of a solar particle stream which flows

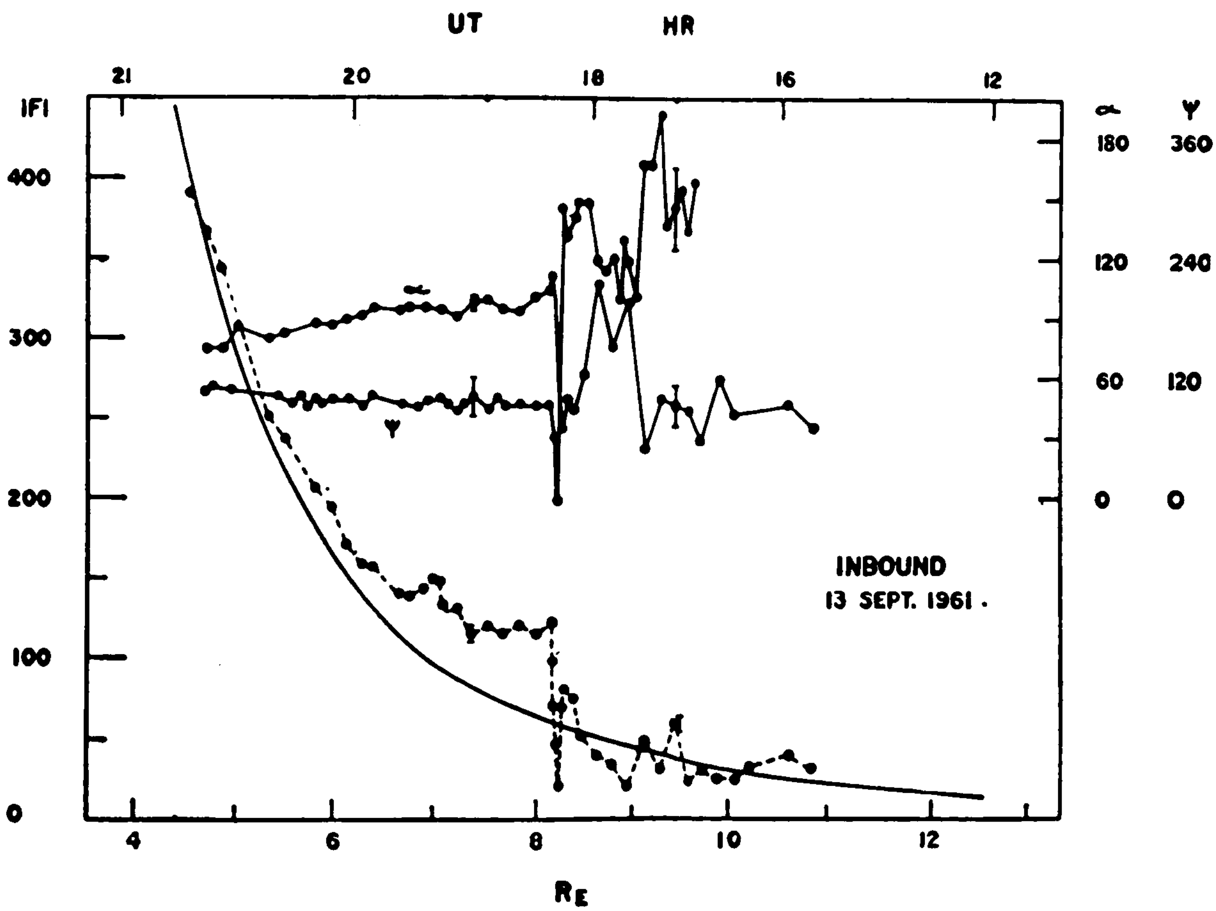

FIGURE 6.—Magnetopause.

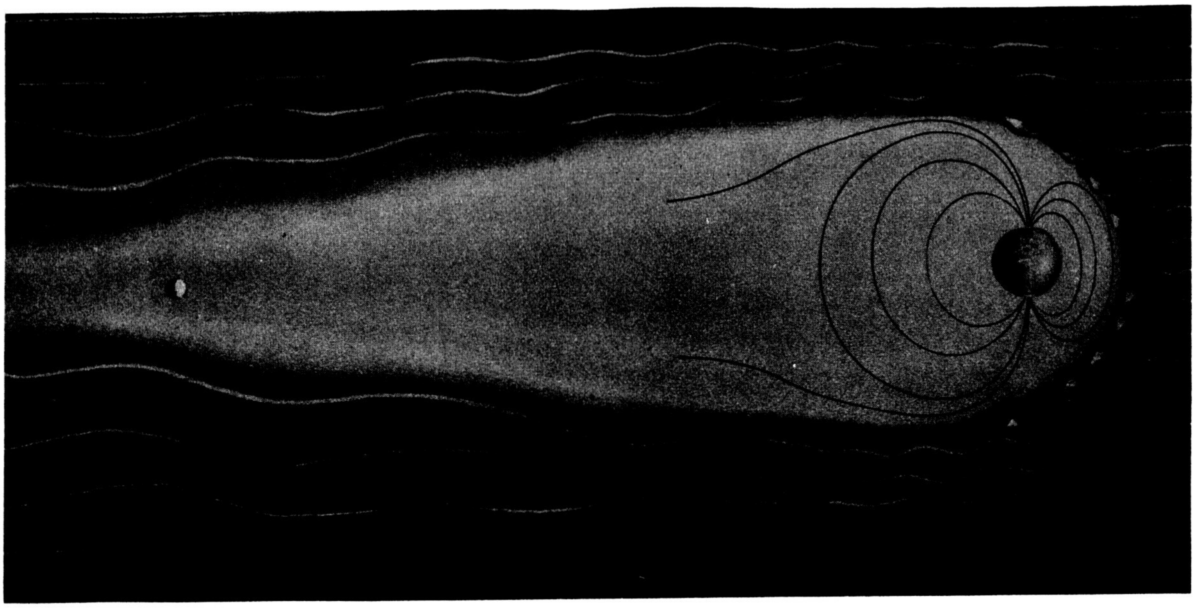

FIGURE 7.—Solar plasma (new concept).

all the time, although it varies in velocity and intensity. It cannot penetrate the magnetic field of the Earth, but divides and flows around the Earth as waters of a stream divide around a boulder. In fact, the closest distance of the solar wind to the Earth is about 10 Earth radii.

The shadow or cavity of the magnetic field of the Earth in this stream should, in principle, extend back indefinitely far into the solar system behind the Earth. However, because the particles of the stream have random transverse velocities, we expect these particles to diffuse together in the shadow of the Earth, thereby filling in the geomagnetic cavity at a distance of several times the diameter of the cavity, or roughly the distance of the Moon from the Earth.

The transfer of energy from the solar wind to the cavity is difficult to estimate. The variable magnetic fields in the solar plasma glue the particles together and give their motion the properties of fluid flow, in spite of the low density, with turbulence to be expected therefore at the solar impact point. The buffeting of the magnetosphere surface associated with this turbulent impact can generate hydromagnetic disturbances in the field lines located just within the magnetopause. These disturbances may propagate down or across the field lines into the atmosphere, where they may transfer energy which appears as atmospheric heating, ionization, auroral disturbances, and magnetic storms—that is, the whole complex of atmospheric disturbances associated with the high geomagnetic latitudes in times of solar activity.

Another aspect of the interaction of the solar plasma with the magnetosphere is the expectation that a "shock wave" will be formed some distance beyond the actual magnetopause. This arises from the supersonic flow of the plasma and the fact that such flow must become subsonic in the vicinity of the Earth. The transition requires a shock wave to be set up which stands off some distance from the magnetopause and has a thickness determined by the ability of the magnetic field to change the bulk motion of the plasma particles. The perturbed magnetic fields corresponding to the shock wave and the intervening transition region have been measured by N. F. Ness of the Goddard Space Flight Center using the IMP spacecraft.

THE ATMOSPHERE OF VENUS

Venus, the closest planet to the Earth, is the third brightest object in the sky next to the Sun and the Moon. It has been observed for centuries and yet, to this day, has remained an enigma to astronomers. The main reason for this lack of information is that the planet is permanently shrouded by a layer of clouds and no surface features have ever been observed.

Apart from reflecting solar radiation, which registers in the visible and near-infrared portions of the

spectrum, a planet also emits its own radiation, which is confined to the far-infrared and microwave regions of the spectrum. Measurements of planetary radiation provide valuable information on the temperature structure of the atmosphere. Such a study of Venus has been hampered by the presence of clouds that are opaque to infrared. However, the small amount of radiation emitted by the planet in the centimeter wavelength region penetrates through the clouds without significant attenuation and can be usefully detected to determine the temperature of the surface of the planet.

First attemps to measure this radiation from Venus were made in 1956 with the radiotelescope of the Naval Research Laboratory. The temperature inferred from the measured radiation intensity was, however, unexpectedly high—of the order of 600° F, which is certainly too hot to support any imaginable form of life. Repeated measurements in the following years have forced a complete revision of our understanding of the surface conditions and the lower atmosphere of Venus.

One way of explaining such a high surface temperature is by assuming the presence of an extremely dense atmosphere composed of large quantities of carbon dioxide and water vapor. These molecules have strong absorption bands in the infrared region of the spectrum, but are relatively transparent to visible radiation. The major part of the sunlight which has not been reflected back by the planet will therefore penetrate through the atmosphere and heat the surface of the planet to a certain temperature.

Venus, whose reflectivity of visible radiation is very high (76 percent of the light received, as compared with some 40 percent for Earth), would be heated to only −40° F by the weak sunlight that filters through the clouds. Because of this cold surface temperature, Venus would emit radiation primarily in the far-infrared region, which would immediately be absorbed by the dense atmosphere. Reradiation from the atmosphere, according to this theory, then sends a major part of the radiation back to the ground, heating it to a very high temperature.

This phenomenon is called the "greenhouse effect" of the atmosphere, an allusion to the glass cover of a greenhouse that is transparent to the Sun's visible radiation but opaque to the infrared radiation emitted from the plants. Thus the infrared is trapped within the greenhouse and heats it up. If it were not for the greenhouse effect of the Earth's atmosphere, the average temperature of the Earth's surface would be a cold —20° F instead of a comfortable 60° F.

In the case of Venus, it is difficult to imagine a greenhouse effect so efficient as to raise the ground temperature to 600° F. This would require an atmosphere of extreme opacity in the infrared, and at the same time considerable transparency in the visible spectrum. Since such an atmosphere would be quite unique, this explanation of Venus' high surface temperature is very controversial.

It is possible that microwave emission from high densities of electrons in the ionosphere of Venus give rise to emission of microwave radiation which results in spuriously high values of the measured temperature. In order to measure the actual temperature, the United States launched the Mariner II Venus flyby, which passed 20,900 miles from the planet and made crucial measurements of the temperature across the disk. The spacecraft was equipped with two radiation experiments, one in the infrared and one in the microwave region.

The radiation emitted by the planet in the microwave region was measured at two discrete wavelengths —13.5 mm, where the radiation is strongly absorbed by water vapor, and 19 mm, which passed through the atmosphere unattenuated and, hence, provided a measure of the ground temperature.

The measurements at 19 mm tested the possibility that the high temperatures observed on Venus originate from a thick ionosphere rather than from the surface. If the ground has a high temperature, then measurements made of the edge or "limb" of the planet should show a slightly lower temperature or "darkening" due to the greater thickness of the intervening atmosphere. If the high temperatures are caused by a high-electron density in the ionosphere of Venus, then the readings at the limb should indicate a "brightening" because of the greater thickness of the ionosphere in the line of sight.

The wavelengths used to measure the infrared radiation of the planet were chosen to give information regarding the temperature at the cloud top and the amount of carbon dioxide above the clouds. Observations of Venus from Earth in the infrared region to date have indicated a temperature of —40° F. As clouds are opaque to infrared, it is believed that this temperature exists at the top of the clouds, similar to the temperature frequently observed at the top of terrestrial clouds.

The Mariner results indicate that the measured values of temperatures were actually correct. There is a limb darkening, indicating that the surface of Venus may actually be at a temperature of 600° K. The infrared radiometer confirmed the earlier temperature of $-35°$ C at the cloud top. It also indicated that there were no breaks in the clouds of Venus during the time of measurement.

EXPLORATION OF THE MOON

The Moon is a uniquely important body in the study of the history of the solar system because its surface has preserved the record of its history remarkably well. The Moon has a negligible atmosphere and no oceans. It is, therefore, unchanged by the processes of erosion which erased the history of the Earth's surface in a relatively short period of time —between 10 and 30 million years.

This is evidenced, in part, by the tens of thousands of craters on the lunar surface, produced by the impact of meteorites which presumably have been colliding with the Moon since its formation. This is perhaps the only physical record which we have of events in the development of the solar system going back to that early time.

Because of this antiquity of the Moon's surface, another remarkable record has been preserved—a layer of cosmic dust which is believed to have rained on it from the solar system since its formation. This dust may be as much as a foot or more in depth and may contain organic molecules and the precursors of life on Earth, providing clues to the origin of physical life.

The most important measurements of lunar properties from spacecraft have resulted from the Russian flights of Lunik II and Lunik III. From the Lunik II magnetometer data Soviet scientists concluded that an upper limit of approximately 100 gammas could be placed on the Moon's magnetic field. In future flights, improvements on this limiting value of the Moon's magnetic field may provide information on the presence or absence of a liquid core within that body. On the Earth the magnetic field is supposed to be associated with currents in the liquid core of the planet. This in turn could have a bearing on our understanding of the formation of the Moon and similar bodies in the solar system.

Lunik III has provided us with the first pictures of the remote side of the Moon. In spite of some blurring, the photographs are still of great interest, for it is possible to distinguish a large number of features resembling the craters and maria on the front face. Perhaps the most interesting feature is the Soviet Mountain Range, a chain extending across the center of the Moon's hidden face. It resembles the great ranges on the Earth and is unlike the mountain formations characteristics of the Moon's front face which seem to be circular crater walls and deposits of debris formed by the impact of large meteorites on the lunar surface.

According to our present ideas, terrestrial mountains result from the combined effects of erosion and wrinkling of the Earth's crust, but these mountain-building forces are believed to have been much less effective on the Moon. The markings of the Soviet Mountain Range could have resulted from the running together of several obscured but independent markings. However, if they continue to appear as a single range in later, more detailed pictures, we may have to revise our theories of lunar structure.

SOLAR PHYSICS

One of the most interesting questions in solar physics is the manner in which energy is transported above the surface of the Sun to heat the chromosphere and corona.

We know that near the center of the Sun, where the temperature is approximately 15 million degrees Kelvin, hydrogen is converted into helium by a variety of nuclear reactions. We also know that the Sun is a self-adjusting system which expands or contracts in order to maintain a precise balance between the energy generation at the center and the energy emission from the surface.

All regular mechanisms of energy transport can carry heat only from a region of high temperature to a region of low temperature. Therefore, in order to carry away from the center of the Sun the heat generated by nuclear reactions, it is necessary for the temperature to fall continuously from the center to the edge. This is in fact the case, the temperature falling from 15 million degrees at the center to 5,800° K at the visible edge of the Sun.

However, above the visible edge, which is called the photosphere, there lies a relatively tenuous region of gas which constitutes the atmosphere of the Sun. This region is divided into the chromosphere and, above that, the corona.

The puzzling fact about these circumstances is that the temperature of the Sun *rises* again from the

photosphere, reaching a value of 1.5 to 2 million degrees in the corona. One of the paramount questions of solar physics is, What constitutes the source of the energy which produces the very high temperatures in the solar corona? Also, What is the mechanism of energy transport which can carry energy without appreciable losses through the dense gases of the photosphere and yet undergo strong losses in the tenuous regions of the corona?

A current belief is that a wave motion—either a sound wave, a hydromagnetic wave, or a gravity wave—carries energy upward from the photosphere and deposits it in the corona. When a sound wave propagates into a region of decreasing density, its amplitude increases and it will steepen into a shock wave. This is a mechanism in which considerable energy dissipation takes place. It appears that hydromagnetic waves are rapidly damped out below the photosphere, but if they can be generated in the region of the chromosphere, they will not tend to be dissipated until they have reached the corona. Magnetic disturbances above the photosphere may be particularly effective in generating these waves. Gravity waves consist of a kind of rolling motion similar to the waves on the surface of the ocean. These may, like sound waves, be generated by the motions of convecting material in the transition layer; they will have a vertical component of propagation and will be dissipated in the corona.

It may be that all three of these mechanisms are effective for the heating of the chromosphere and corona. If this is the case there may be a steady heating of the corona, upon which is superimposed a localized heating associated with magnetic activity. Thus, the heating of the corona is expected to depend upon the magnetic structure in the outer layers of the Sun. This is observed in many phenomena; in particular, in sunspot regions where the magnetic-field strengths are higher than is normal on the Sun's surface, both the chromosphere and the corona have a higher than normal temperature.

The behavior of the chromosphere and the corona is most easily observed by studying the ultraviolet emission from the Sun, since in the ultraviolet region the amount of light emitted from the photosphere greatly decreases, whereas the higher temperatures in the chromosphere and corona are responsible for the presence of large numbers of emission lines. The most important emission lines are due to hydrogen and helium. In order to understand solar surface physics in more detail, it is essential to obtain observations of the time variations of these emission lines as indicators of the time variations of behavior in the chromosphere and corona.

The first experiments in this direction were very successfully accomplished by the flight of the first Orbiting Solar Observatory, which was launched on March 7, 1962. It gave several months of data, continuously monitoring a number of different wavelength regions for emission from the Sun.

Particularly interesting are the data for the 11th through the 22d of March, 1962. At the beginning of this period the Sun was in an exceptionally quiet condition, but as the period progressed the Sun became more and more active, until on March 22 there was a flare of importance 3. Experiments revealed that the Lyman alpha line of He II at 304 Å increased by some 33 percent during the interval, and during the flare itself the line increased by an additional 14 percent. The lines of Fe XV at 284 Å and Fe XVI at 335 Å also increased in intensity by a factor of 4. At longer wavelengths, the Lyman alpha line of hydrogen was observed to increase in intensity by 6.8 percent during the flare.

Very interesting results were also obtained in the X-ray region, 1 to 10 Å. During the quiet period a flux was observed which was 360 times the theoretical background which would be obtained from a corona at a temperature of 1.8 million degrees Kelvin. This indicates that nonthermal processes are present and important in the corona under even the quietest solar conditions.

A continuing series of Orbiting Solar Observatories is planned in which these interesting phenomena can be monitored continuously during future years.

X-RAYS AND GAMMA RAYS

The space research program is not confined to the discovery of new facts about the solar system. It also represents an important opportunity for the astrophysicist to extend his knowledge of more distant parts of space through observations at wavelengths for which photons do not penetrate through the atmosphere. The principal regions involved are the X-ray and gamma-ray region, the ultraviolet, the infrared, and long-wave length radio waves. The early rocket and satellite measurements of X-rays and gamma rays have been particularly interesting to physicists because they suggest several possible new types of phenomena in space.

X-rays and gamma rays can be produced by a variety of high-energy processes. These processes include collisions between high-energy nucleons which can create neutral pions, which in turn decay to give gamma rays exceeding 50 Mev in energy. Fast electrons can produce X-rays or bremsstrahlung when they pass close to a nucleus. Fast electrons can also collide with photons of visible starlight and increase the energy of the photons into the X-ray and gamma-ray region. If radioactive nuclei are produced and dispersed in space between the stars, some of them should emit characteristic gamma-ray energies which might be detected. If positrons are produced in dense regions of matter, such as stellar surfaces, then upon being slowed down and annihilated they will emit the characteristic gamma rays of 0.51 Mev energy. If neutrons are produced near stellar surfaces and are slowed down and captured by the overwhelmingly abundant hydrogen that is present, then these will provide characteristic capture gamma rays with an energy of 2.31 Mev. Finally, we may note that if objects should exist in space with surface temperatures of some millions of degrees Kelvin, then photons in the X-ray region will be emitted by thermal processes from their surfaces.

Preliminary measurements now exist of the fluxes of X-rays and gamma rays in a number of different energy intervals. A general background of X-rays of a few thousand electron volts energy was observed in a rocket flight by R. Giacconi, H. Gursky, F. R. Paolini, and B. B. Rossi. A general background radiation of gamma rays in the region near 1 Mev energy was measured in the Ranger 3 flight by J. R. Arnold, A. E. Metzger, E. C. Anderson, and M. A. Van Dilla. A small but still significant flux of gamma rays with energies exceeding 50 Mev was observed with the Explorer XI gamma-ray satellite by W. L. Kraushaar and G. W. Clark.

A number of attempts have been made to explain the presence of these background X-rays and gamma rays. Most mechanisms thus far examined appear quantitatively inadequate to explain the observed fluxes. One promising explanation is due to J. E. Felten and P. Morrison, who suggested the importance of the inverse Compton effect, in which the high-energy electrons present in the cosmic rays collide with photons with engeries of the order of 1 electron volt which are emitted from stars. Following such a collison, the photons can easily be raised to the observed range of X-ray and gamma-ray energies, depending upon the energies of the electrons with which they collide.

Calculations by Felten and Morrison were based on this effect. A flux will be emitted by the outer halo region of our galaxy if the observed flux of high-energy electrons at the position of the Earth exists throughout this large outer region of the galaxy. Electrons in the halo fail to account for the observed X-ray and gamma ray fluxes by some 2½ orders of magnitude. However, if it were to be assumed that the high-energy electrons are present throughout all of space with the same intensity with which they are observed near the Earth, then a background radiation of some 30,000 times that which would be produced within the galactic halo would be observed. Evidently, such high fluxes of electrons cannot exist throughout all of space. One percent of such a flux of electrons can be expected to give a backround of X-rays and gamma rays which fits the observations very nicely.

However, perhaps the most interesting questions concerning the celestial X-rays have been raised through the discovery of discrete sources by Rossi and his colleagues and by H. Friedman, S. Bowyer, T. A. Chubb, and E. T. Byram of the Naval Research Laboratory. Both groups have observed a strong X-ray source in Scorpius which is not coincident with any conspicuous object. Friedman has suggested that this object is a neutron star having a surface temperature of several million degrees, and that the X-rays are due to thermal emission from the surface layers. Rossi and his colleagues have determined from atmospheric absorption measurements that if the Scorpius source has a thermal spectrum its temperature is approximately 8 million degrees Kelvin. Friedman and his colleagues have also observed X-rays from the direction of the Crab Nebula, the remnant of the supernova explosion of 1054 A.D.

Neutron stars are hypothetical objects which form one class of degenerate stars, the other class being the degenerate white dwarf stars, which are observed. A typical density for matter in a white dwarf star is 10^6 gm/cm^3, and the electrons form a degenerate gas which exerts sufficient pressure to maintain the stars against further contraction. If mass were to be added to such a star, the central region would have to become denser in order to supply the additional pressure required to support the additional mass. There is a relativistic upper limit to the mass of white dwarf

stars, but before this limit is reached the energies of the degenerate electrons have become so high that the nuclei are forced to undergo multiple electron capture reactions, and the nuclei dissolve mainly into neutrons, with only enough protons and electrons left to prevent the neutrons from undergoing their usual mode of decay into electrons and protons.

At 10^{15} gm/cm^3 or more, densities comparable to those in the atomic nucleus, this neutron-rich nuclear matter itself becomes degenerate, and it is expected that stable stars could be constructed of it. Such stars may be formed in the central regions of more massive stars when these stars undergo supernova explosions and blow off most of their mass. Recent work by D. Morton, E. E. Salpeter, H. Y. Chiu, S. Tsuruta, and A. G. W. Cameron indicates that the surface temperature of a neutron star is likely to lie between one and two orders of magnitude below its central temperature. Thus, if such stars are formed with central temperatures over 10^9 degrees Kelvin, as would be likely in a supernova explosion, then their surface temperatures are likely to be many millions of degrees for several thousand years.

If these speculations are correct, it is to be expected that several dozen neutron stars can be detected in our galaxy as X-ray astronomy improves its techniques. The neutron-star hypothesis predicts a specific thermal shape for the X-ray spectrum of the Scorpius source, with the possibility that the composition of the surface will be revealed by characteristic absorption edges. It should not be long before decisive tests of this hypothesis have been made.

PRACTICAL USES OF SATELLITES

Chairman
HARRY J. GOETT
Director
NASA Goddard Space Flight Center

INTRODUCTION TO

PRACTICAL USES OF SATELLITES

HARRY J. GOETT
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In introducing this session, *Practical Uses of Satellites,* it would be interesting to discuss a little its relationship to the previous sessions—in particular to the one on *Machines in Space.* That session was a report on what we in NASA call *scientific satellites* and, as Dr. Dessler said, "These satellites are involved in projects and search for knowledge that is considerably in advance of the technological use of this knowledge." In this session we are discussing what we call *application satellites,* which we are either already using in a very practical technical sense or are right on the threshold of actual use in space. The difference between the two sets of satellites is really more one of degree than it is of essence. We might draw the parallel between the work of the research pathologist, for instance, and that of the practicing physician; of the physical scientist on the one hand and of the engineer on the other. Somewhat in the same sense, the good that the man on the street gets out of these application satellites is a little more immediate than what he expects from the scientific satellites. The Space Age began only a little more than 6 years ago when the United States launched its first satellite. It is rather surprising and represents a very rapid development that we are ready—are using these satellites for the useful purposes that will be discussed in this session. In this session there will be a change of pace because our three speakers will be discussing primarily the accomplishments of the first 6 years rather than the anticipations of the future, although there will be some discussions of "things to come" in space.

N64-30340

NAVIGATION SATELLITES

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One of the earliest suggestions for a practical operating satellite system to accomplish a practical terrestrial objective to receive financial support was a system for global navigation. The system, supported initially by the Department of Defense's Advanced Research Projects Agency, was the outgrowth of work done by William Guier and George Weiffenbach at the Applied Physics Laboratory of The Johns Hopkins University in the very sophisticated analysis of the doppler shift from the first Sputnik. The specific suggestion for a possible navigation system, based on a similar precise analysis of the doppler shift resulting from the relative motion of an artificial satellite and a ground observing station to yield an accurate determination of the position of the ground station from a knowledge of the satellite orbit, was due to Frank McClure of the Applied Physics Laboratory, and the first special NASA award for contribution to space technology was given to Dr. McClure for this concept.

The detailed system to accomplish global navigation with the aid of special artificial satellites was embodied in a program under the code name of Transit in 1959, and responsibility for the development was transferred from ARPA to the Navy in 1960. The proposed system concept, as widely described at that time, is shown in figure 1. It includes a constellation of four satellites in polar orbits, with orbital planes at 45° intervals, which transmit two coherent stable frequencies. Also, modulations are imposed on these frequencies which signify the contents of a satellite memory which can be loaded from the ground. This transmission is a simple communication channel which makes available to the user a recent determination of the satellite orbit. In addition to obtaining the orbit information, the user also measures the doppler shift exhibited on the received frequency from the stable satellite oscillator because of the relative motion of the transmitter (satellite) and receiver (ground point fixed on a rotating earth). Because of the transmission and reception of two coherent frequencies, it is possible to make a good approximate correction for the major ionospheric refraction effect.

Progress on this system, as reported in the open literature up to 1963, was very encouraging. In particular, enough was published during this period to establish the fact that the limitation on accuracy for the system would be determined by the knowledge of geodesy since the largest uncertainty would result from the knowledge of the satellite orbit which, in turn, was limited by our knowledge of the force field which controls the satellite orbit. Unfortunately, in March 1963, a change in policy resulted in the classification of this project so that we can not report in an unclassified manner the current status of this specific program.

NASA has been observing the progress of this program to determine whether or not it would meet general civilian and commercial needs for a global navigation system. It has tentatively determined that the program has certain disadvantages, as far as general purpose, nonmilitary use is concerned, that are sufficiently restrictive to warrant a serious search for alternative systems. Quite recently there has been announced the results of a study program, carried out by General Electric (GE) that proposes an alternative system that is believed, by some, to more nearly meet the needs of a general-purpose civilian system.

The general concept of the GE system is to establish a system of a large number of satellites distributed with random phase about four different orbits at an altitude of some 6,000 miles. In addition, the system has six ground stations strategically located about the globe. It can be shown that with an appropriate,

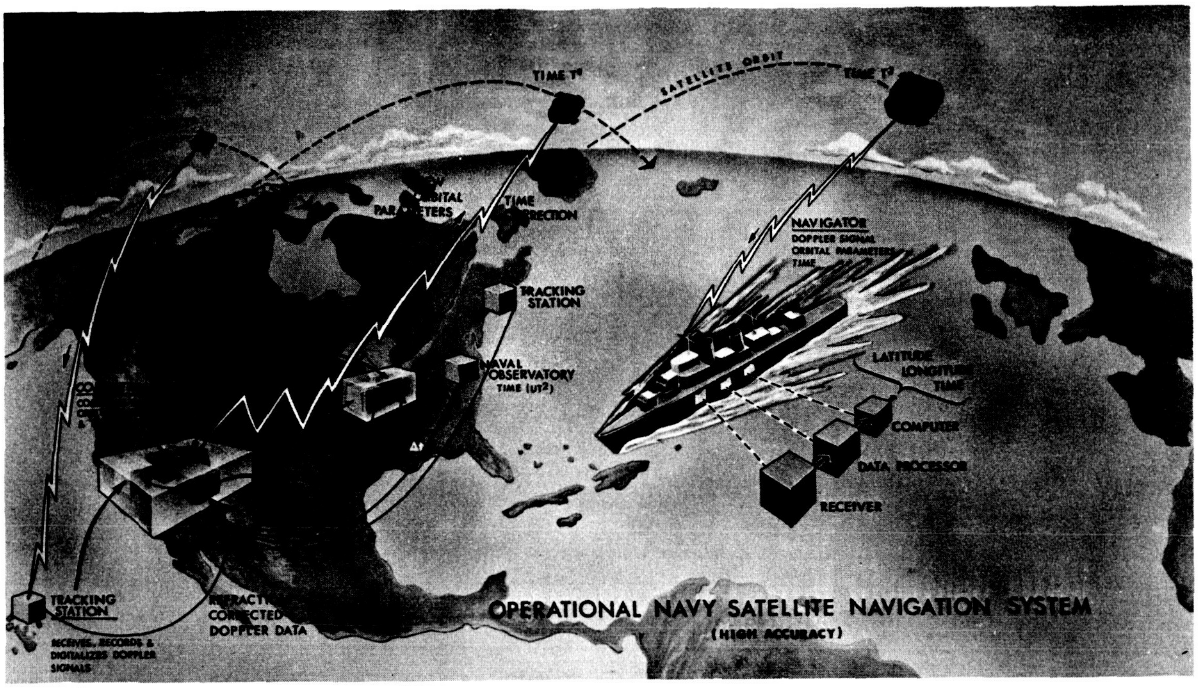

FIGURE 1.—*Operational Navy satellite navigation system.*

relatively large, number of satellites there will always be essentially, for any potential user, two satellites which are simultaneously within his line of sight and within the line of sight of one of the six ground stations. When a user desires his position he sends out a simple signal which is relayed by all satellites within line of sight. A ground station which receives this request for position from two separate satellites responds by sending out a time impulse. This time impulse is relayed by the two satellites from which the request was received on to the user and is simply echoed back by the user via the same two satellites to the ground station. By measurement of the time difference in these paths, the ground station, which, of course, knows the satellite position, can compute a triangulation for the user and establish his position, or at least two alternative positions. This information is then sent to the user, again by a satellite as a relay point. The user generally can readily select the correct one between the two possible positions since they usually differ quite widely.

The considerations which lead to this system proposal were, of course, quite different from those which dictated the system selection of the Navy. In the case of the Navy's system, the entire cost of establishing and maintaining the system and paying for user equipment is all carried by the same organization, and the proper consideration is to meet the objectives with a minimum overall cost of system plus user equipments. There also are a relatively small number of user equipments, so that it is quite reasonable to pay a substantial amount for user equipment if by so doing the system establishment and maintenance costs can be reduced. For a general-purpose civilian system, however, in which user equipment cost must be paid by the private shipowners, the system will attract users only if shipboard equipment cost can be held quite low. Thus, in principle, it is reasonable to consider systems which are appreciably more expensive to establish and maintain if this more complex system can result in greatly reduced user-equipment cost. But, of course, the deeper question of whether it is appropriate for the Government to provide such a service as a subsidy or whether, alternatively, the economic considerations should provide for eventual amortization of the system costs by charges to the user must, of course, be decided ultimately by the Congress or the President.

The purpose for raising this issue, at this time, is simply to take the opportunity to suggest to all within earshot that the economic considerations will, or at least should be, very important in the decision-making

process to come, and that it may not be too late to consider alternatives which could make an exceedingly large effect on the outcome of these economic considerations.

First, it is apparent that NASA, in making a determination of the suitability of the Navy's navigation approach for civilian needs, simply considered the system as proposed and did not investigate the question as to whether it was possible to modify or augment the system to meet the requirements of civilian use for considerably less money than would be required by the development of a totally new system. Secondly, and perhaps more important, if the pattern established in the past is followed, the decision with regard to implementing a civilian navigation system will be made on the premise that a satellite system as a navigation aid will have to justify itself economically on the assumption that it accomplishes nothing else. Now the fact is that the satellite system required to implement the GE navigation proposal is to all intents and purposes simply another intermediate altitude, random-orbit communication system. It may have rather specific requirements with regard to reproducibility of time delay but this is a minor technical detail. If the United States does establish, through the ComSat Corp., or in any other way, a midaltitude, random-orbit communication satellite system, adding to these satellites the requirement that they be able to accept and relay the signals and messages required for a navigation system of the GE type might make very little difference in the design and costs of the satellite. In this case, the economic consideration involved becomes markedly different.

It is granted that the exceedingly complex governmental and industrial boundary conditions that exist in the communication satellite area make this suggestion very difficult to implement, but surely somewhere there is a big enough system.

Whatever system is used to establish navigation on a worldwide basis with the aid of artificial satellites, it is clear that the accuracy of the system is dependent, among other things, on the accuracy with which the satellites can be tracked. And this, in turn, is dependent on the precision with which the forces, primarily gravitation, which act on the satellite, are known. In short, an accurate description of the gravitational force field is a prerequisite to accurate navigation by satellites.

Although it is not quite so obvious, actually the same information is required to establish an Earth-based global navigation system. In fact, since the Earth is largely water covered and elevations, even on land, are based on "sea level," the "shape" of the Earth is controlled by the gravitational field; that is, the liquid surface of the Earth will form an equipotential surface in the gravitational field (with proper allowance for the effect of rotation). Thus, knowing the gravity field is equivalent to knowing the shape of geoid, i.e., the equipotential surface. And knowing the shape of the Earth is obviously necessary to provide accurate global navigation even by Earth-based systems such as Omega.

In summary, progress in global navigation accuracy, with or without satellites, is dependent on progress in geodesy. For this reason, it seems appropriate to indicate here the current status of geodesy. It is particularly appropriate to discuss this matter since geodesy constitutes another of the practical applications of artificial satellites for accomplishing a terrestrial objective.

Before the advent of artificial satellites, the Earth was considered to be an oblate spheroid, that is, an ellipsoid of revolution with a circular equator but a polar flattening. The first major departure from this shape was the determination by O'Keefe that there was an appreciable peaking at the north pole and flattening at the south pole which constituted a north-south dissymmetry. This fact, referred to in the press by the phrase "pear-shaped" (figure 2), was deduced

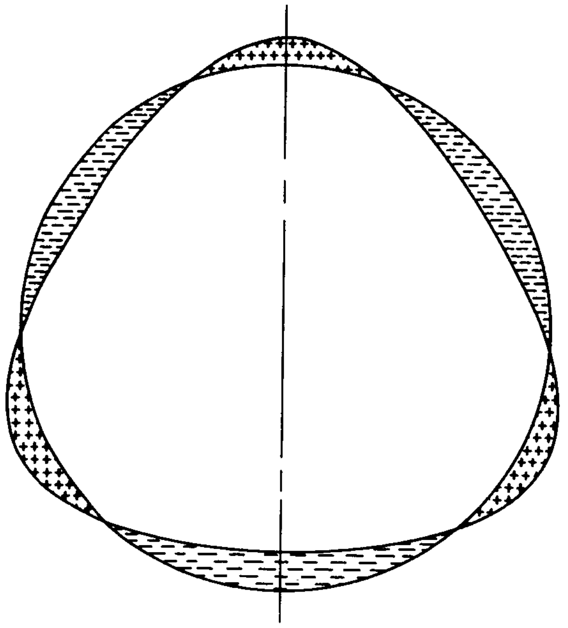

FIGURE 2.—Pear-shaped Earth.

from satellite tracking. The next major announced departure from the earlier model was given by Izsak with the statement that optical satellite tracking clearly indicated that the earth's equator was elliptical. This fact has been determined independently by Newton at the Applied Physics Laboratory, based on doppler tracking results.

It is customary, in geodetic research, to express the gravitation field in terms of a series expansion in spherical harmonics:

$$V(r, \varphi, \lambda) = -\frac{K}{r}\left[1 + \sum_{l=2}^{\infty} \sum_{m=-l}^{l} \frac{J_{l_m}}{r^l} Y_l^m(\varphi, \lambda)\right]$$

$J_{2,0}$ = 1st oblateness term(4,5)
$J_{4,0}$ = 2nd oblateness term(4,5,7)
$J_{3,0}$ = Pear-shaped term(4,5,6)
$J_{5,0}; J_{7,0}$ = Higher order odd-harmonics(4,5,6)
J_6 = Higher order even harmonics(7)
$J_{2,2}; J_{2,-2}$ = 1st elliptic equator term(8,9,10)

In this expansion, the terms which are longitude independent are called zonal harmonics and those which depend on longitude (like the elliptic equator term, $J_{2,2}$) are nonzonal harmonics. The announcement of the pear shape of the Earth and of the elliptic equator corresponded to an approximate determination of $J_{3,0}$ and $J_{2,2}$, respectively.

In 1963, Guier, of the Applied Physics Laboratory, used data from the doppler tracking of three satellites at different inclinations to make a determination of all nonzonal harmonics through the fourth order. Table I summarizes the data used, and table II indicates the data fit obtained with this determination. It is of interest that the overall data consistency of about 0.06 nm (nautical mile) is contrasted with about 0.2 (nm) 1 year earlier and something like 1 nm 4 years earlier.

At about the same time, Cohen (at Dahlgren), Kaula, and Izsak also made determinations of some or all of these harmonic coefficients. The results are shown in tables III, IV, and V.

Shortly after this determination of the harmonic coefficients through the fourth order, a polar satellite, which could be tracked accurately with doppler, became available. The results were quite surprising; namely, that the same geodetic coefficients which made possible the tracking of three separate satellites to a consistency of about 0.06 nm could allow no better than about 0.15 nm in tracking a polar satellite. At this point Newton made a new determination of the

TABLE I.—*Summary of doppler data used.*

Satellite designation	Inclination, deg	Semi-major axis, km	Eccentricity	No. of individual satellite passes	No. of distinct station location	No. data groups, satellite orbits	Av. no. of passes per group	Av. time span per group (hr)
1961αη1	32.4	7410	0.010	87	9	8	11	15.9
1962βμ1	50.1	7510	.007	199	15	9	22	22.7
1961o1	66.8	7320	.008	155	13	10	16	23.3
Totals				441	18	27		

TABLE II.—*Final data root-mean-square residuals*

Satellite	Symmetric component (along-track),	Antisymmetric component (slant range),	Total residuals	
	Miles	Miles	Miles	Nautical miles
1961αη1	78.1	81.9	113.2 =	0.061
1962βμ1	62.0	60.7	86.8 =	0.047
1961o1	73.6	84.6	112.3 =	0.061
		RMS total	102.3 =	0.055

TABLE III.—*Nonzonal harmonic coefficients of the geopotential, $n = 2$ Value (x 10^6)*

Coefficient	Guier	Cohen	Kaula	Izsak
C_2^1 ---	*(0.0178)	....	....	....
S_2^1 ---	*(−0.0348)	....	....	....
C_2^2 ---	1.680	1.836	1.19	0.968
S_2^2 ---	−0.638	−0.987	−1.10	−0.400

*C_2^1 and S_2^1 should be negligible. They are listed in this table as one indication of the accuracy of the results.

TABLE IV.—*Nonzonal harmonic coefficients of the geopotential, $n = 3$ Value (x 10^6)*

Coefficient	Guier	Cohen et al.	Kaula	Izsak
C_3^1 ---	1.768	....	1.10	1.12
S_3^1 ---	0.194	....	−0.12	0.06
C_3^2 ---	0.2858	....	0.115	0.091
S_3^2 ---	−0.025	....	0.027	−0.183
C_3^3 ---	0.1480	....	−0.043	0.071
S_3^3 ---	0.1410	....	0.102	0.124

TABLE V.—*Nonzonal harmonic coefficients of the geopotential, $n = 4$ Value (x 10^6)*

Coefficient	Guier	Cohen et al.	Kaula	Izsak
C_4^1 ---	−0.5688	−0.6785	−0.199	−0.288
S_4^1 ---	− .4597	− .3757	+ .436	− .321
C_4^2 ---	.05987	.1011	− .0067	.035
S_4^2 ---	.2661	.2688	.0755	.123
C_4^3 ---	.0790	.1580	.0299	.0215
S_4^3 ---	− .0028	−0.036	.0096	.0148
C_4^4 ---	− .00785	....	− .0051	.0097
S_4^4 ---	0.00656	....	0.0116	0.0163

TABLE VI.—*Determinations of the odd harmonics units of 10^{-6}*

Harmonic	1	2	3	Kozai
J_3 ---	−2.673 ± .059	−2.676 ± .055	−2.703 ± .27	−2.562 ± .007
J_5 ---	−0.088 ± .038	−0.086 ± .035	−0.052 ± .34	−0.064 ± .007
J_7 ---	−0.439 ± .042	−0.442 ± .044	−0.507 ± .63	−0.470 ± .010
J_9 ---	....	....	+0.055 ± .51	+0.117 ± .001

zonal harmonics (which were not well determined by Guier's approach) and improved the tracking of the polar satellite to about 0.1 nm without hurting the tracking of the lower inclination satellites (table VI).

The geoid that results from these investigations is shown in figure 3. We are approaching the point of being able to make a new determination, based on very high-quality data from four satellite inclinations, including one in polar orbit, of all coefficients through sixth order. However, it is clear that the needs of the geodesy program can only be met by firing still more satellites, specifically instrumented to enable precision tracking, in a variety of orbits.

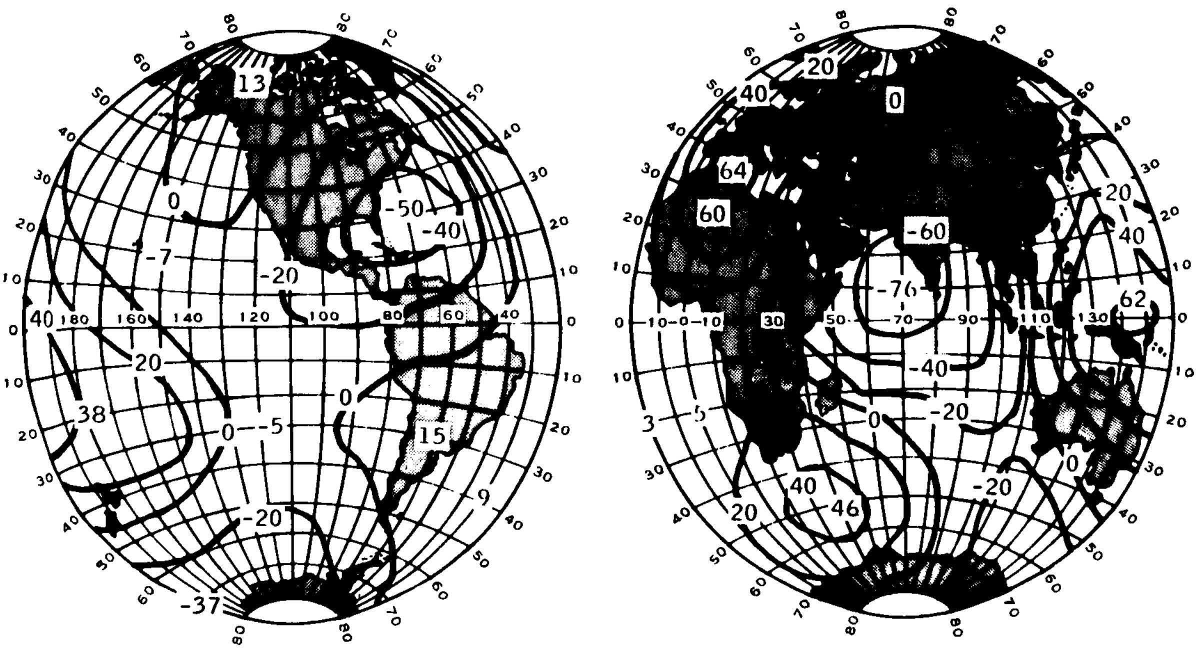

FIGURE 3.—Doppler geiod of satellite (Guier, 1963).

N64-30341

WEATHER SATELLITES

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This past year has been a momentous one for the Nation's meteorological satellite program. A year ago, Tiros VI was transmitting television pictures of the cloud cover of the Earth. Tiros VII was being prepared for its launch, the Nimbus spacecraft subsystems were in their advanced stages of qualification and preparation for integration into the spacecraft itself, the program was proceeding along lines that had been established in 1960 when the interagency responsibilities for the various aspects of the program were defined, and we in the U.S. were busy preparing to meet with the U.S.S.R. to discuss the implementation of a joint meteorological satellite program.

Since then, Tiros VI has ceased its transmissions after 1 year of operation, VII and VIII have been successfully launched and are still operating, the Nimbus spacecraft and the system are in the final stages of qualification and preparation for launch, and the direction and emphasis of the program have been sharply changed, and new interagency relationships established. The U.S.-U.S.S.R. cooperative program stands exactly where it did in the spring of 1963. However, the international aspects of the program entered an entirely new phase with the use of the automatic picture transmission system on Tiros VIII, permitting the receipt of picture data from the satellite at many ground stations throughout the world.

THE TECHNICAL ACCOMPLISHMENTS

The phenomena the Tiros satellites have observed and the data collected by the TV and infrared sensors aboard the spacecraft are impressive. It would be impossible to present even a fair sampling of the 340,000 pictures that have been received and analyzed and of the 5,000 orbits of visible and infrared radiation data that have been taken, or to summarize the more than 100 scientific and technical papers that have been published. The new observations and the operation of the Tiros system have become so routine that there exists a constant threat of our being swamped by the flood of information. Indeed, the quantity of data to be received, processed, and assimilated—particularly for operational applications—is the major problem for the meteorological satellite program.

The routine nature and the global scope of the operation are best illustrated by the Tiros Daily Progress Report which is prepared by the NASA and U.S. Weather Bureau personnel in the Tiros Technical Control Center at Goddard Space Flight Center and distributed to the interested executives of NASA and the U.S. Weather Bureau and to the managers of the program. Report No. 209, dated 20 April 1964, selected at random, reads:

TIROS DAILY PROGRESS REPORT NR 209
20 APRIL 64

TIROS I NOT TRANSMITTING

TIROS II BEACON TRANSMISSION 108.00 MC AND 108.03 MC.

TIROS III BEACON TRANSMISSION ON 108.03 MC.

TIROS IV BEACON TRANSMISSION ON 136.23 MC AND 136.92 MC.

TIROS V BEACON TRANSMISSION ON 136.23 MC AND 136.92 MC.

TIROS VI NO BEACON TRANSMISSION. PERIODIC INTERROGATIONS SCHEDULED TO CHECK SPACECRAFT SUBSYSTEMS.

TIROS VII

1. PICTURES TAKEN—128 TV PICTURES WERE TAKEN OF WHICH 124 WERE METEOROLOGICALLY USABLE.

2. UNUSUAL PICTURES—NONE.

3. SIGNIFICANT STORMS OBSERVED—NONE.

4. ENGINEERING REPORT—

A. SPACECRAFT: FOUR SYSTEM TWO TV READOUTS WERE PROGRAMMED. THREE SEQUENCES ALARMED ON TIME. ONE SEQUENCE ALARMED LATE (1 MIN).
B. COMMAND AND DATA ACQUISITION OPERATIONS: FOUR FRAMES READOUT AT WALACQ WERE NOISY UNUSABLE DUE TO USE OF THE MEDIUM GAIN ANTENNA.

5. METEOROLOGICAL REPORT—

5 NEPHANALYSES WERE OBTAINED FROM 4 ORBITS INTERROGATED FOR TV DATA. 5 WERE RETRANSMITTED BY FACSIMILE. 4 CODED NEPHANALYSES WERE TRANSMITTED BY TELETYPE. 48 PICTURES WERE RECEIVED AT NWSC BY PHOTOFACSIMILE AND 5 OF THESE WERE RETRANSMITTED. ORBITS 4520 TO 4534 OCCURRED DURING THIS PERIOD. THE AREAS COVERED BETWEEN 50 DEGREES N AND 20 DEGREES S INCLUDED EASTERN SIBERIA, KAMCHATKA, NORTH PACIFIC OCEAN, RED SEA, ARABIA, ARABIAN SEA, INDIAN OCEAN, UNITED STATES, GULF OF MEXICO, CARIBBEAN SEA, CENTRAL AMERICA, AND WESTERN CANADA.

SIGNIFICANT METEOROLOGICAL FEATURES OBSERVED WERE FRONTAL BAND SOUTH OF KAMCHATKA.

FRONTAL BAND NORTH ATLANTIC OCEAN NEAR 40 DEGREES NORTH AND 52 DEGREES WEST.

POSSIBLE ITC NORTH PACIFIC OCEAN 5–10 DEGREES NORTH BETWEEN 155 AND 170 DEGREES WEST.

POSSIBLE ITC INDIAN OCEAN ALONG EQUATOR BETWEEN 51 AND 62 DEGREES EAST. POSSIBLE ITC NORTH ATLANTIC OCEAN NEAR EQUATOR BETWEEN 10 AND 30 DEGREES WEST. POSSIBLE SQUALL LINE OKLAHOMA TO SOUTHEAST KANSAS.

LANDMARKS OBSERVED WERE: KAMCHATKA, SEA OF OKHOTSK, RED SEA, FT. PECK RESERVOIR, GULF COAST AND CUBA.

TIROS VIII

1. PICTURES TAKEN—224 TV PICTURES WERE TAKEN OF WHICH 222 WERE METEOROLOGICALLY USABLE. 7 APT PICTURES WERE TRANSMITTED. THE AREAS COVERED INCLUDED: AUSTRALIA, NEW ZEALAND.

2. UNUSUAL PICTURES—NONE.

3. SIGNIFICANT STORM OBSERVED—NONE.

4. ENGINEERING REPORT—

A. SPACECRAFT: EIGHT SYSTEM ONE TV READOUTS WERE PROGRAMMED. SEVEN SEQUENCES ALARMED ON TIME. PLAYBACK PICTURES WERE NOT RECEIVED ON ONE READOUT DUE TO TV DROPOUTS DURING THE PREVIOUS INTERROGATION.

B. COMMAND AND DATA ACQUISITION OPERATIONS: NINE STEPS OF ONE TELEMETRY READOUT WERE LOST DUE TO OPERATION DIFFICULTIES AT WALACQ.

5. METEOROLOGICAL REPORT—

7 NEPHANALYSES WERE OBTAINED FROM 8 ORBITS INTERROGATED FOR TV DATA. 7 WERE RETRANSMITTED BY FACSIMILE. 5 CODED NEPHANALYSES WERE TRANSMITTED BY TELETYPE. 30 PICTURES WERE RECEIVED AT NWSC BY PHOTOFACSIMILE AND NONE OF THESE WERE RETRANSMITTED. ORBITS 1751 TO 1764 OCCURRED DURING THIS PERIOD. THE AREAS COVERED, BETWEEN 50 DEGREES S AND 15 DEGREES N INCLUDED, NORTH AND SOUTH PACIFIC OCEANS, INDONESIA, INDIAN OCEAN, SOUTH CHINA SEA, BAY OF BENGAL, NORTHERN SOUTH AMERICA, AUSTRALIA, AND CARIBBEAN SEA.

SIGNIFICANT METEOROLOGICAL FEATURES OBSERVED WERE CIRCULATION CENTER INDIAN OCEAN 37 DEGREES SOUTH 131 DEGREES EAST.

FRONTAL BAND EASTERN AUSTRALIA.

FRONTAL BAND WEST OF AUSTRALIA.

POSSIBLE FRONTAL BAND INDIAN OCEAN 35S 48E TO 47S 60E.

POSSIBLE FRONTAL BAND SOUTH PACIFIC OCEAN 33S 100W TO 43S 90W.

POSSIBLE FRONTAL BAND SOUTH PACIFIC OCEAN 27S 147W TO 33S 134W.

POSSIBLE ITC WESTERN INDONESIA 5 DEGREES NORTH TO 10 DEGREES SOUTH.

POSSIBLE ITC INDIAN OCEAN 6 TO 15 DEGREES SOUTH BETWEEN 65 AND 80 DEGREES EAST.

POSSIBLE ITC NORTH PACIFIC OCEAN 1 TO 10 DEGREES NORTH BETWEEN 110 AND 129 DEGREES WEST.

POSSIBLE ITC SOUTHEAST OF HAWAII 4 TO 11 DEGREES NORTH BETWEEN 135 AND 149 DEGREES WEST.

LANDMARKS OBSERVED WERE: AUSTRALIA, INDIA, CEYLON, ECUADOR.

Tiros Television Picture Data

The Tiros spacecraft and ground stations are illustrated by figure 1. Figures 2 to 13 include some Tiros television pictures; recognizable landmarks and other geographic features are often the most interesting features of such pictures.

In figure 2, a view of the Middle East, the Red Sea is easily identified. Crete and the Aegean Islands are the outstanding features of the picture of Greece (fig. 3). Figure 4 shows the Great Lakes, and figure 5 shows the northeastern area of the United States in sharp contrast to the ocean with Cape Cod and Long Island especially clear.

The enormous amount of data in a Tiros picture—1 million bits per picture (in the language of the computer and communication engineers)—makes necessary the reduction of the information to a format that can be readily transmitted to others for their use. Nephanalyses (cloud analyses) are produced from the

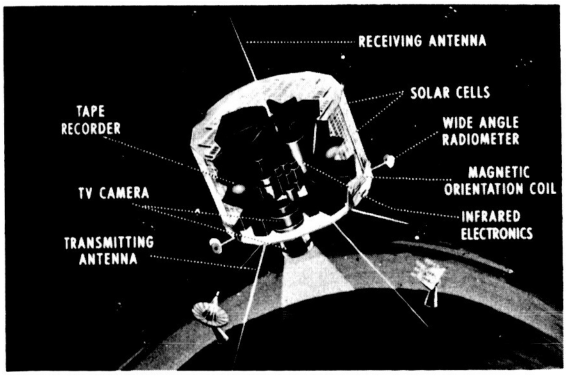

FIGURE 1.—The Tiros spacecraft.

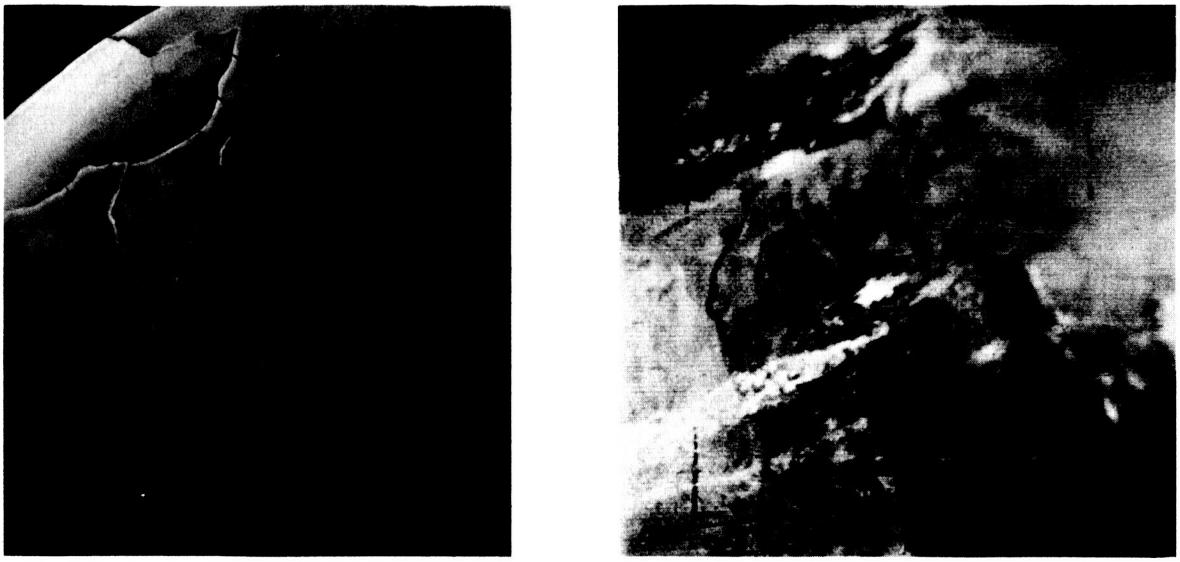

FIGURE 2.—Tiros picture of the Middle East.

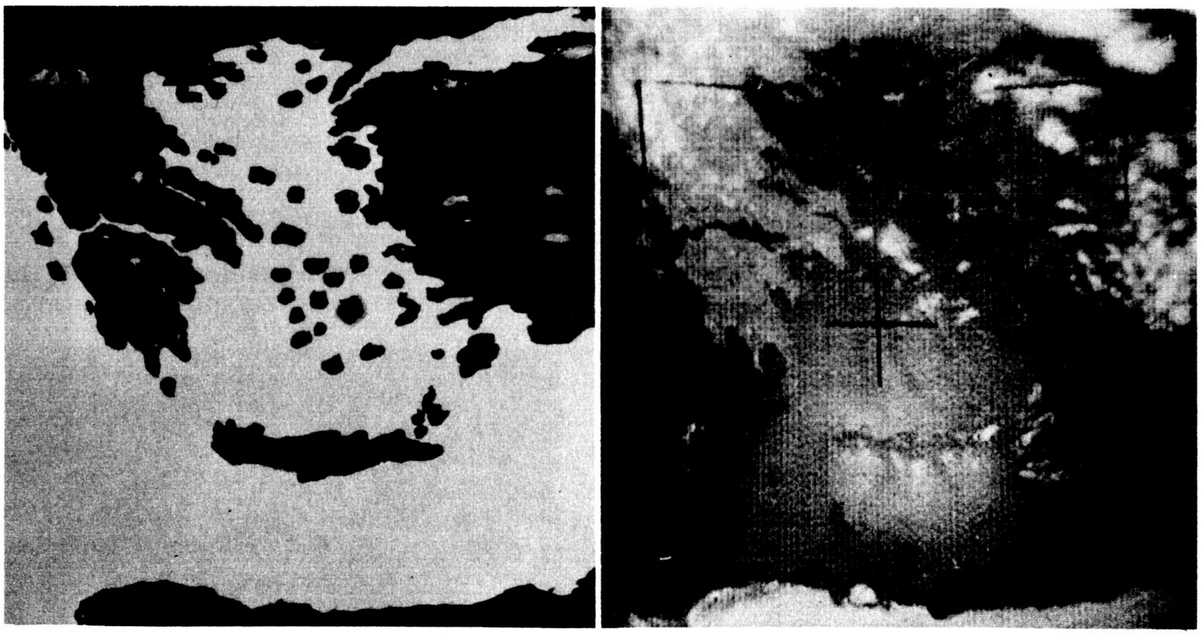

FIGURE 3.—Tiros photograph of Greece.

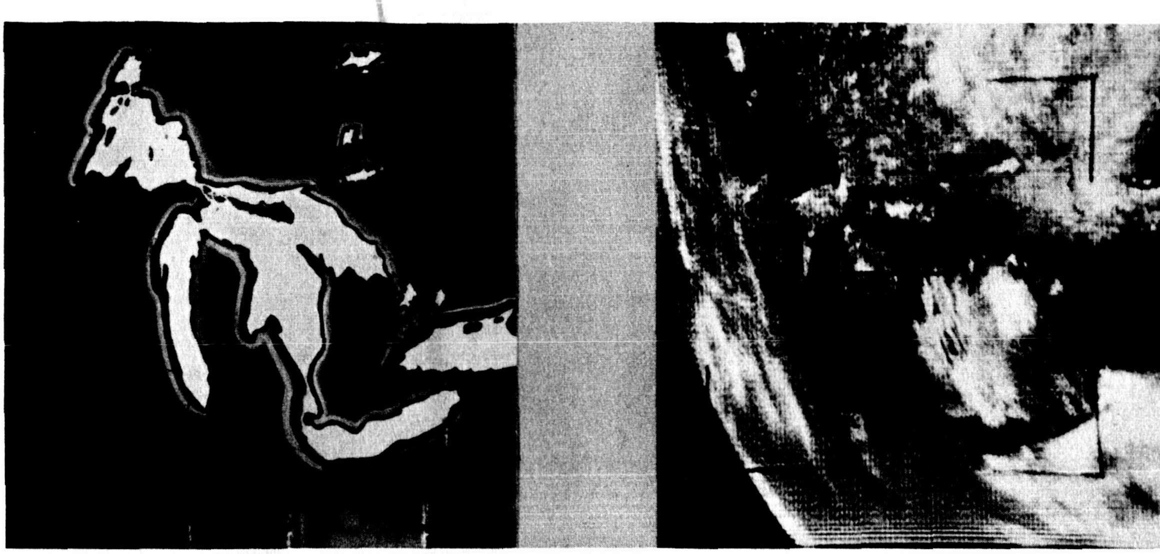

FIGURE 4.—Tiros photograph of the Great Lakes.

FIGURE 5.—A Tiros picture showing the northeastern United States.

pictures and transmitted by facsimile to the various users.

Tiros observations in data-sparse areas are made available to the meteorological community through nephanalyses of the picture data (fig. 6). A graphic shorthand is used to describe the types and distribution of clouds.

Figure 7 is a photograph of Florida with severe squall line and thunderstorm activity west of Tampa. This is another example of data from an area of few observations. The rain at Tampa was so heavy that the weather radar equipment was "blinded" and the extent of the storm activity undefined. Hurricane Anna in 1961 was one of the hurricanes observed and extensively studied by Tiros. Figure 8 shows the hurricane on July 21st off the coast of Venezuela.

Figure 9 is a cloud analysis for September 11, 1961, during an unusually busy hurricane season. Tiros observed the three hurricanes seen in this artist's rendition of the nephanalyses: Carla, Debbie, and Esther. On this same day, Tiros also observed the remains of hurricane Betsy in the North Atlantic and two full-blown typhoons in the Pacific Ocean off Japan. Esther was discovered when a ship in the Atlantic had reported high winds, and the U.S. Weather Bureau asked NASA if Tiros could take pictures of the area. Within 3 hours of the request from Miami, Tiros pictures of the hurricane were in the hands of the meteorologists.

Many other cloud phenomena have been observed by Tiros. Jet stream clouds and mountain clouds are shown in fig. 10, a photograph of the Red Sea area. In figure 11, the diamond-shaped cloud, which was about 50 miles square, was associated in time with severe thunderstorm and tornado activity as the surface analysis on the right shows.

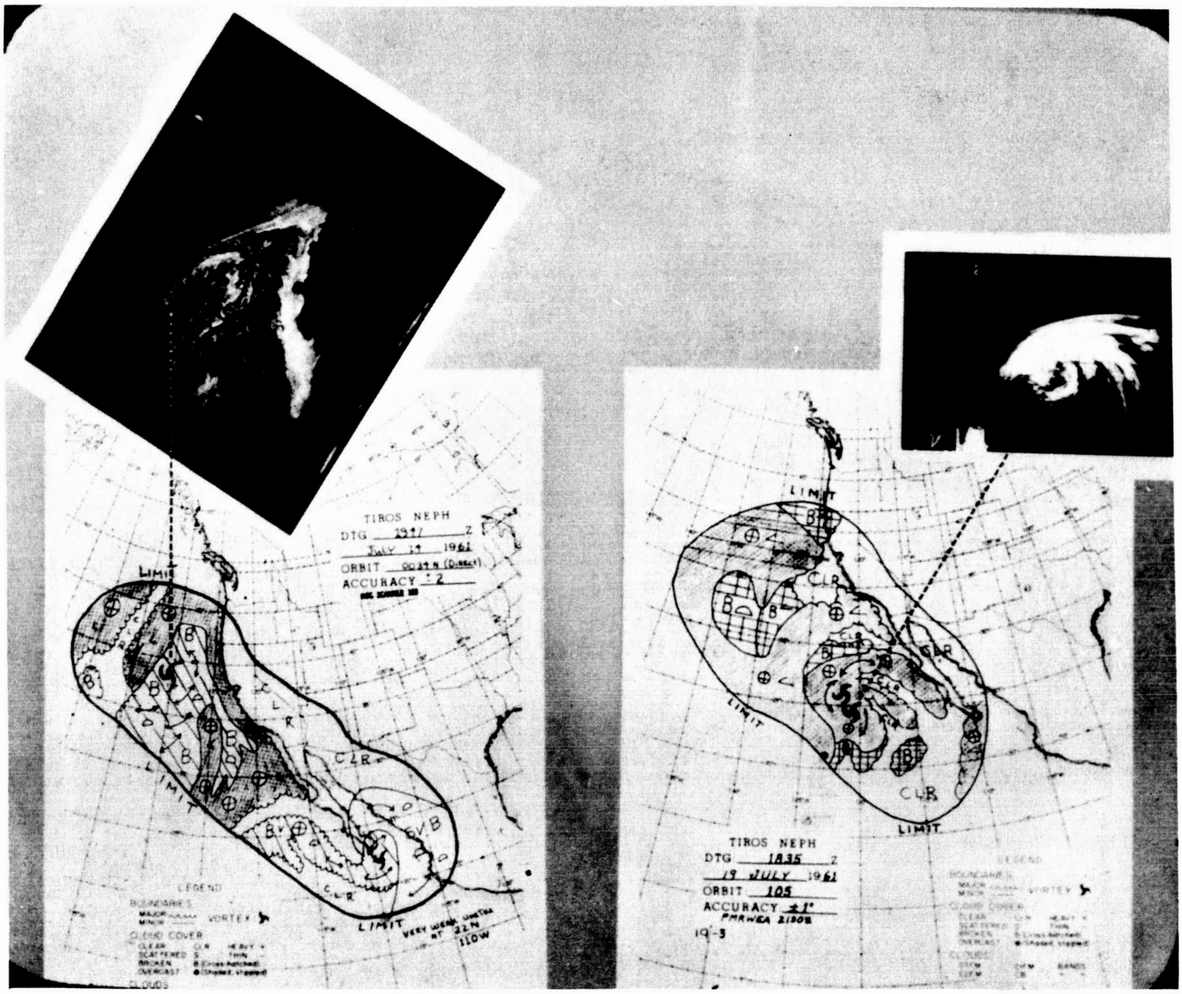

FIGURE 6.—Tiros III observations in a data-space area.

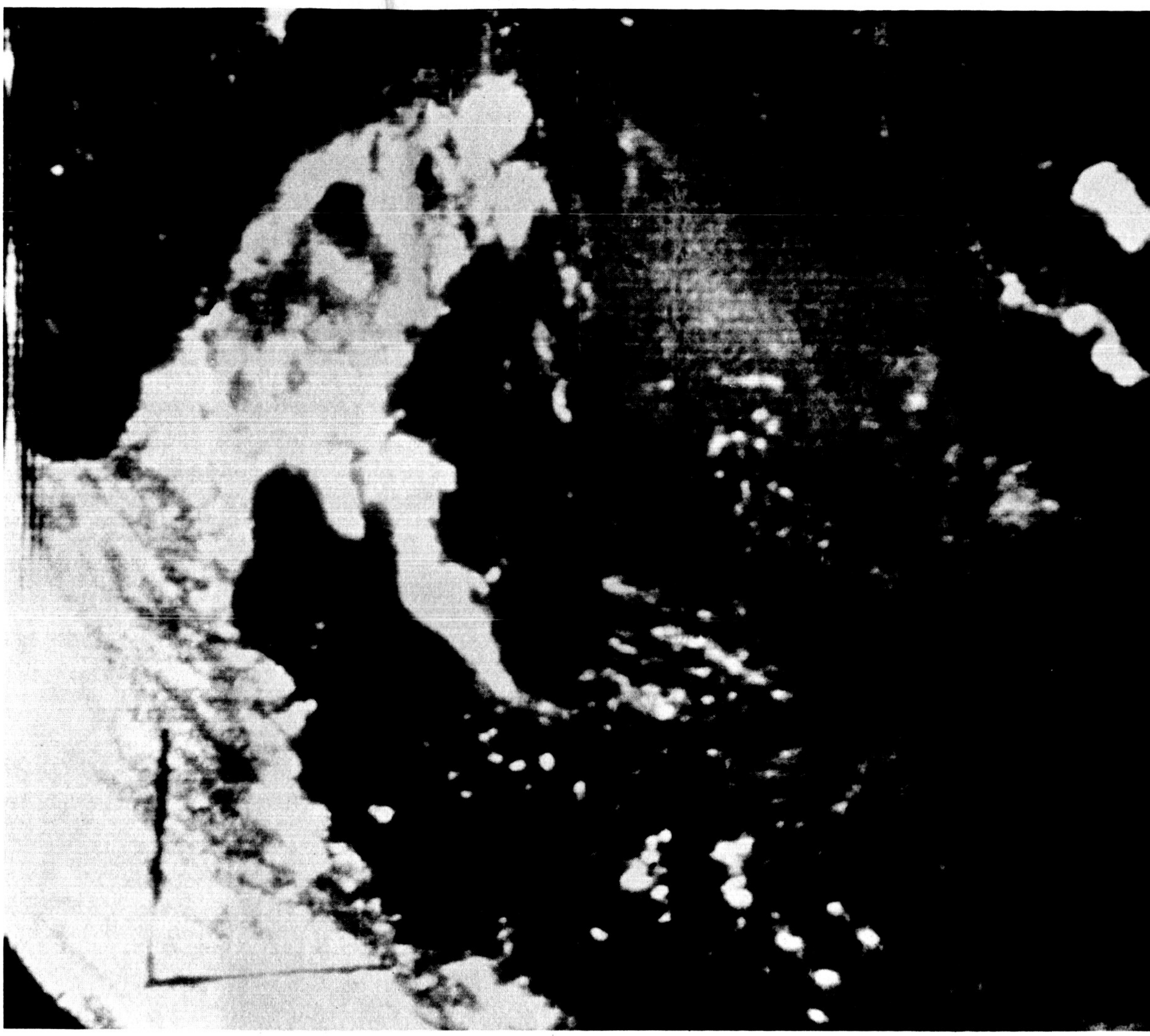

FIGURE 7.—A photograph of Florida showing severe squall line and thunderstorm activity west of Tampa.

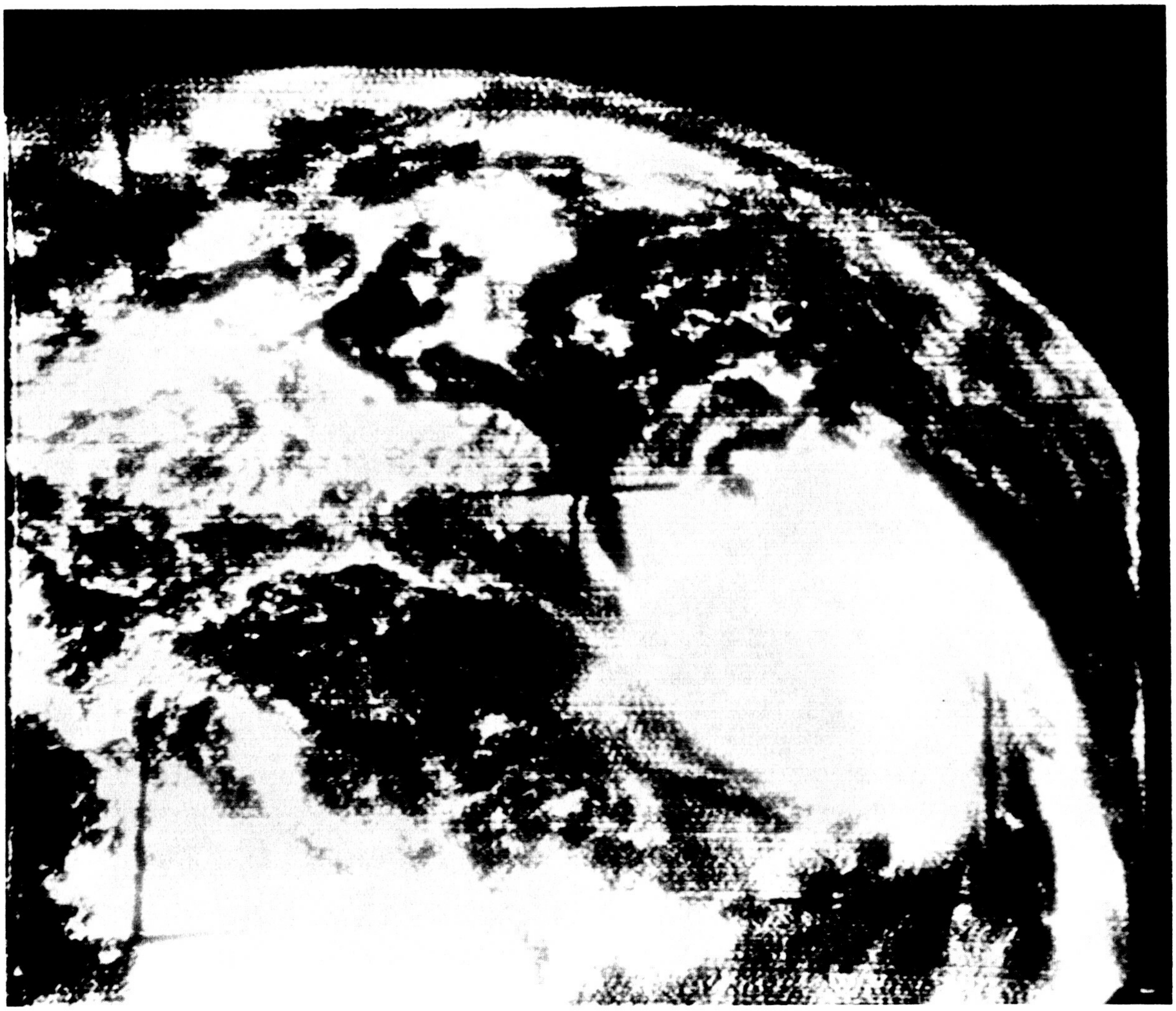

FIGURE 8.—Hurricane Anna in 1961, off the Venezuelan coast.

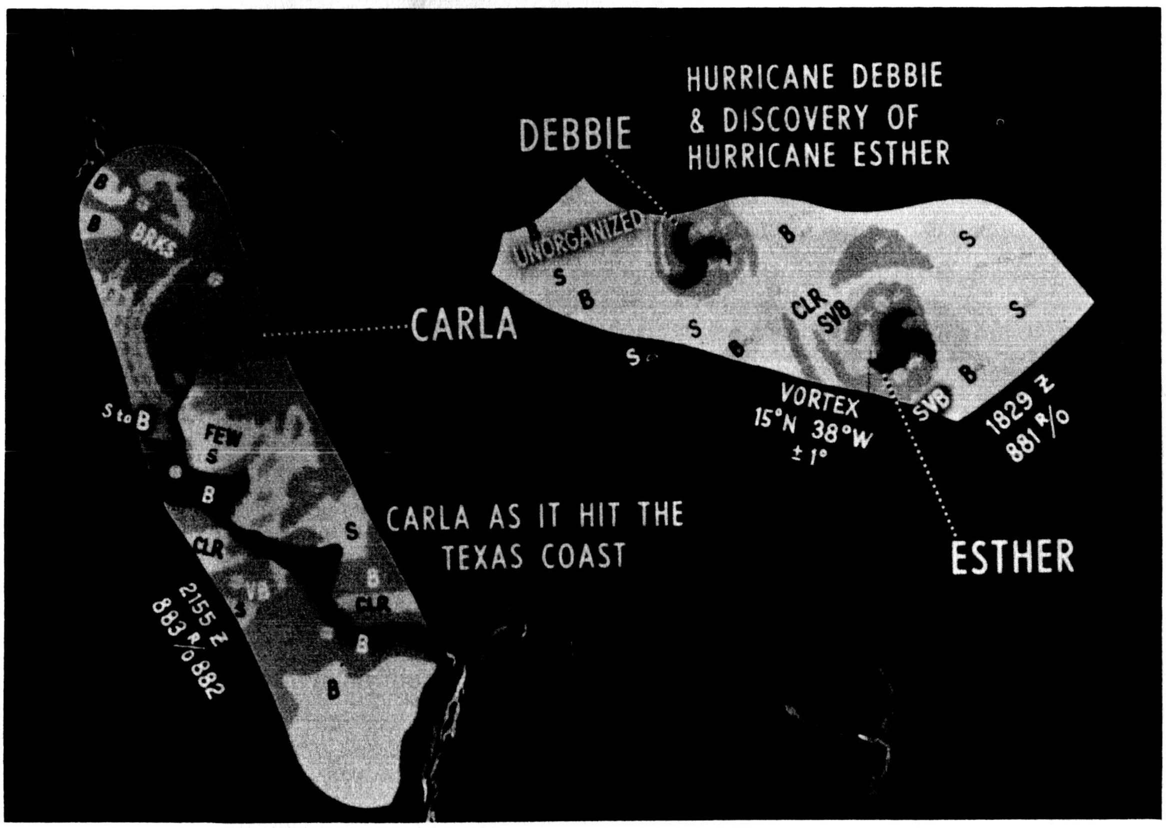

FIGURE 9.—A detailed cloud analysis made on September 11, 1961.

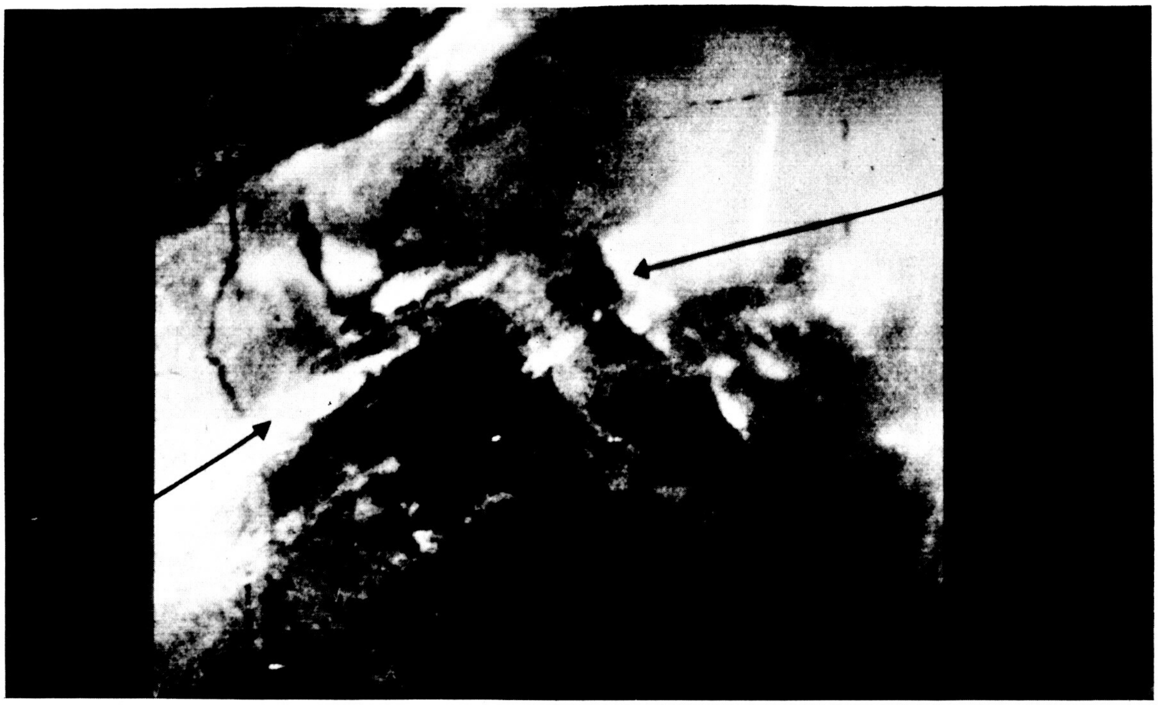

FIGURE 10.—Jet stream and mountain clouds on April 4, 1960.

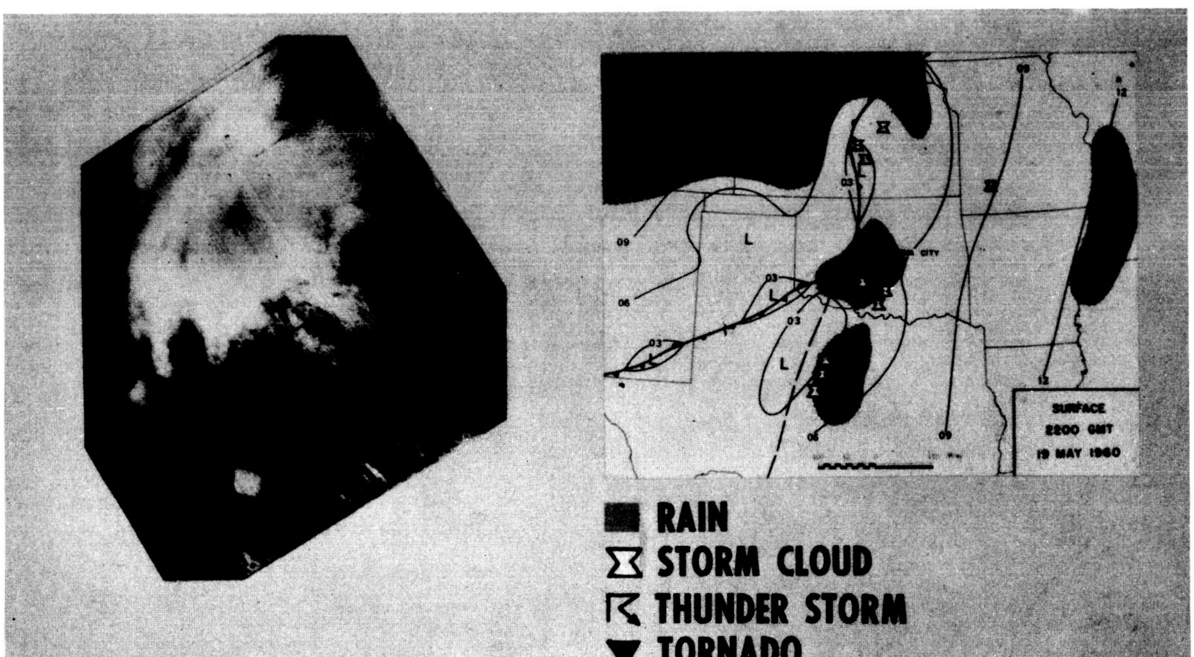

FIGURE 11.—Cloud patterns associated with a tornado.

Ice reconnaissance has been another accomplishment of the Tiros series. This was particularly true of Tiros II which carried a narrow-angle camera, in addition to the standard, to achieve 0.2-mile resolution. The high resolution mosaics of Tiros II photographs in figure 12 show Anticosti Island in the Gulf of St. Lawrence and the ice conditions on 2 days, March 23 and 29, 1961. The movement of the ice and its freeing of the island during this 6-day period are quite apparent. This reconnaissance has been of considerable interest to the Canadian Government and to the shipping companies using the gulf. Normally, extensive aircraft overflights are used for such reconnaissance.

Radiation Data from Tiros

The year 1963 saw the establishment of the Tiros five-channel radiometric measurements as tools of greatest potential for the exploration of the Earth's atmosphere for meteorological purposes. This instrument, which measures the emitted and reflected electromagnetic radiation from the Earth and the atmosphere, maps the spatial distribution of the energy by using the spin of the satellite to generate the scan line and the motion of the satellite along its orbit to advance the scan line. By using filters to limit the sensitivity of the various channels to different spectral regions in the visible and infrared, it has proved possible to measure the distribution and height of clouds during both day and night and the distribution and amount of water vapor in the tropopause, to map the distribution of temperature in the stratosphere, and to observe a number of other important physical phenomena. These radiometric measurements have the critical advantage over the cloud-picture data in that they are quantitative; that is, they provide accurate numerical values of the parameter under observation.

Figure 13 is a black-and-white reproduction of a photograph of a global map of the distribution of clouds and surface features as observed by the window channel. On the original, shades of color indicate a measure of the radiation intensity seen by the satellite radiometer. Radiation intensities are expressed in equivalent blackbody temperatures ranging from 300° K to 225° K. The radiation patterns provide a remarkably good description of the cloud cover prevailing over the globe at that time. High-radiation intensities can be seen over clear skies, particularly over the north African and Arabian deserts, where radiation is received from the very hot Earth surface. In contrast, low-radiation intensities are observed over cloudy areas where radiation is emitted by the relatively cold-cloud surfaces. Radiation minima indicating high clouds exist at high southern latitudes where a number of typical winter storms are in progress; over the North Pacific where a series of frontal systems range from Japan to the Gulf of Alaska; and over the tropics, north of the equator. A major tropical storm, Flossie, is located over the Philippines.

The 48° inclination of the orbit limits the possible data coverage to a broad zone between about 55° N. and 55° S. The particular geographic locations of the ground stations which command the readout of the data stored on magnetic tape in the spacecraft limit the number of consecutive orbits which can be interrogated to eight, and create permanent wedge-shaped gaps in the possible data coverage near 90° E. (north) and 90° W. (south). Unfortunately, in this case orbit 59 was missing, producing additional gaps over central Africa and the central Pacific.

When viewing is directly downward, the instantaneous field of view of the radiation sensor covers an area on the surface of the Earth having a diameter of about 65 km. As the nadir angle increases, the area becomes increasingly elongated in the direction viewed. The maximum nadir angle employed in the construction of this map was 58°. On July 16, 1961, the Tiros III orbit was positioned relative to the Sun such that the southbound transit of the satellite occurred in sunlight and the northbound transit occurred within the Earth's shadow; hence, the portion of the map lying east of the diagonal running from 20° S., 45° E. to 20° N., 90° E. consist largely of nighttime data, whereas the portion west of the diagonal consists of daytime observations. For comparison, a surface weather map based on conventional meteorological observations was superimposed on the radiation data.

Figure 14 is a photograph of Florida, a detail of the global map of figure 13. It shows on the west coast of the peninsula a bright cloud area—high cumulus clouds associated with intense thunderstorms. This detailed cloud structure also shows on the global radiation map.

The radiation data are now yielding maps of isolines that look much like the daily weather maps one sees in the newspapers, except that the satellite does not measure pressure. Figure 15 is a map of

FIGURE 12.—High-resolution mosaics of Tiros II photographs showing the ice conditions surrounding Anticosti Island on March 23 and 29, 1961.

FIGURE 13.—A global map of the distribution of clouds and surface features as observed by the window channel.

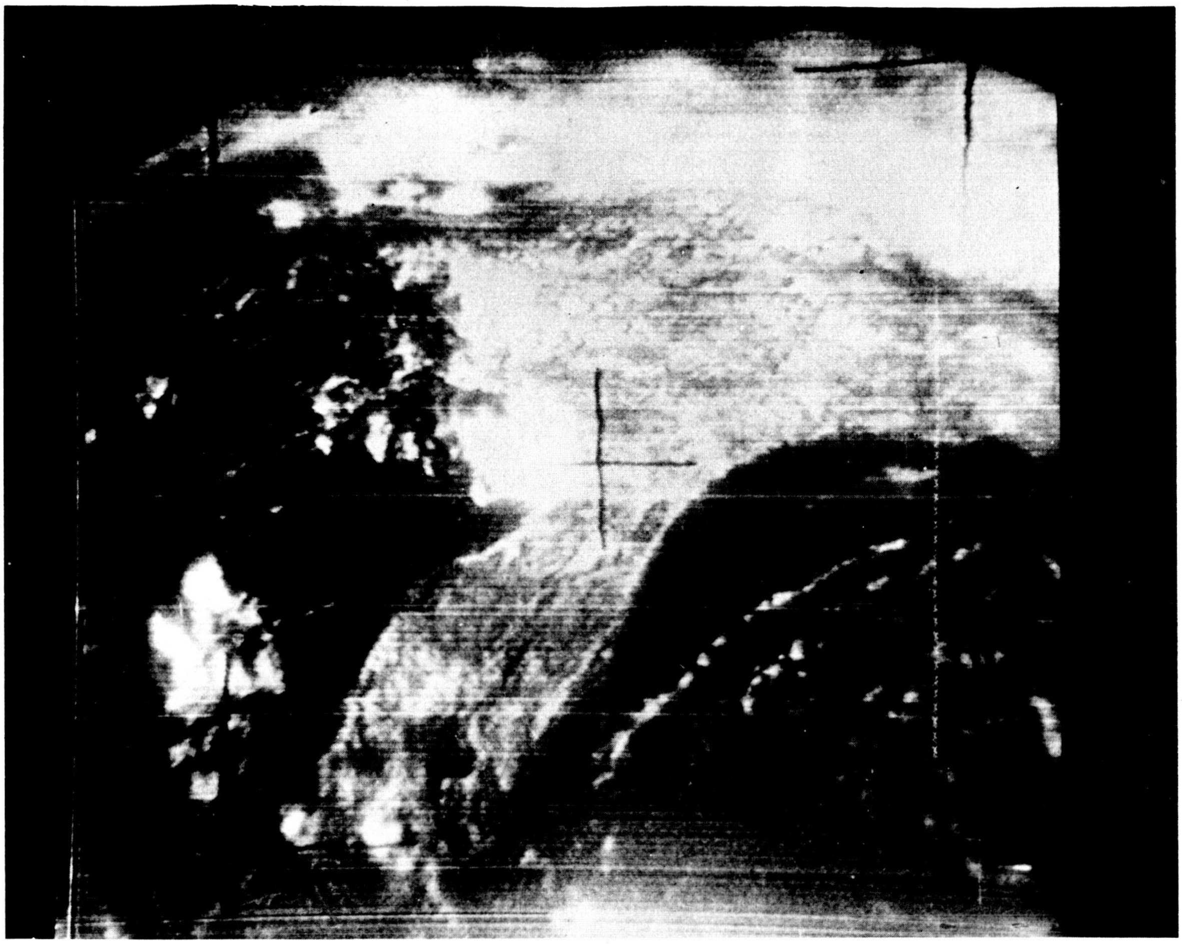

FIGURE 14.—Florida, a detail of the figure 13 global map.

Earth with the isotherms (lines of equal temperatures) in the stratosphere, as measured by the 15-micron radiometer channel plotted. Such phenomena as the Aleutian *high* and the weak summer polar vortex of the southern hemisphere are readily identified. Troposphere relative humidities over the United States were measured by the 6.3-micron *water vapor* channel of the Tiros radiometer (fig. 16). This is a new type of observation, which, frankly, we do not yet know how to use in the routine weather forecasting work.

One final Tiros accomplishment of the past year has been the exercising of the Automatic Picture Transmission (APT) system developed for Nimbus. The objective was to provide a means of transmitting cloud pictures of daylight areas of the Earth directly to the user of the data, whether he be on land, at sea, or in the air. Further, it was a requirement that the ground equipment be inexpensive so that the international community could make extensive use of the system.

In operation, the satellite-borne vidicon camera system takes a picture and over the following 200 seconds transmits it directly without external command. All APT ground stations, which consist of an inexpensive antenna and receiver and a relatively expensive facsimile machine, capable of tracking the satellite during the 200 seconds, can receive the picture. Thus, the local user receives a cloud picture of the area surrounding him (about 1,000 miles square). Figure 17 is a photograph of one type of ground station antenna being used for APT reception.

Figure 18 shows an APT ground station, completely ready for use, consisting of only two low racks. Figure 19 is an example of an APT photograph from Tiros VIII showing the west coast of the United

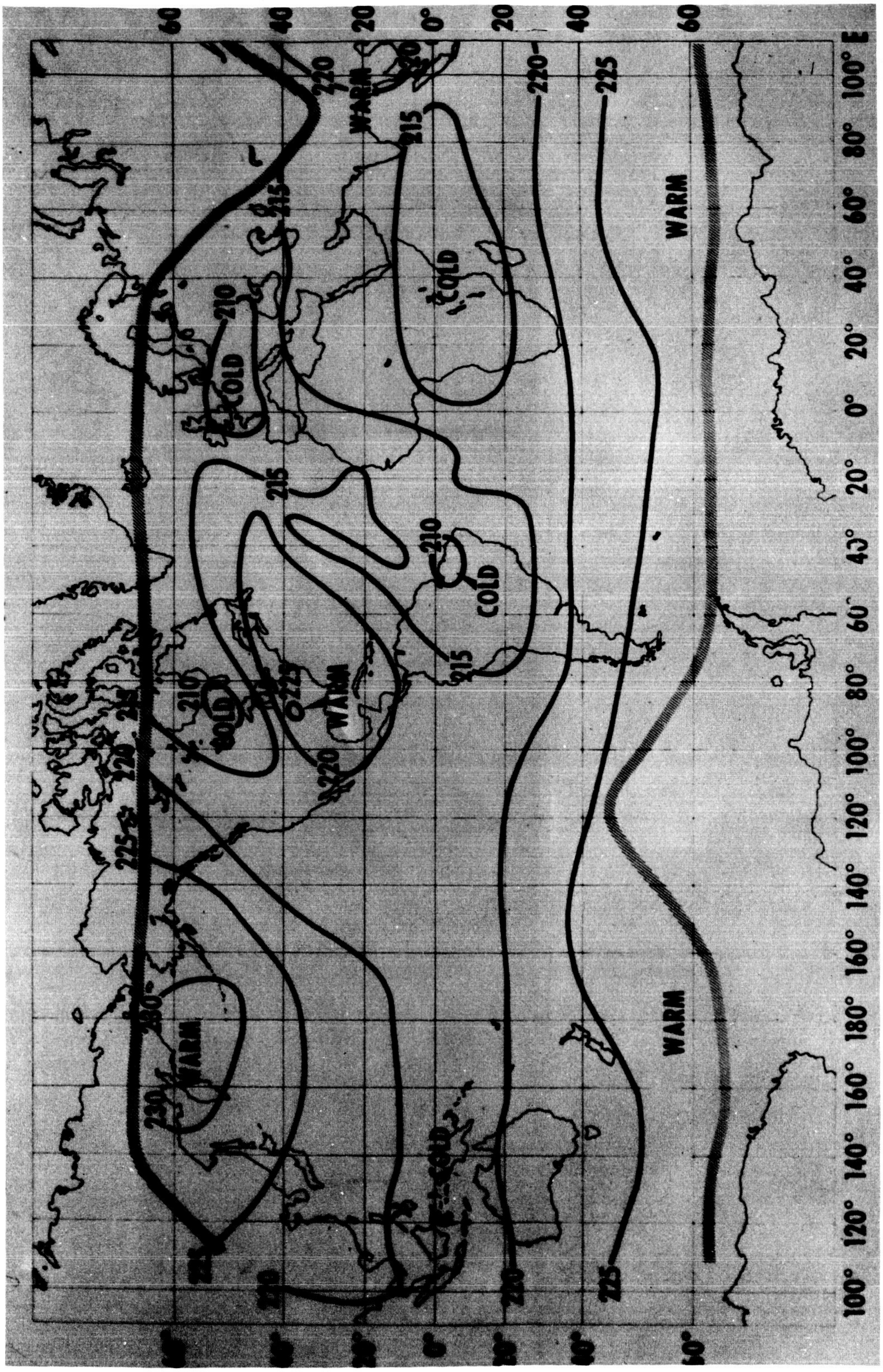

FIGURE 15.—Map of the Earth indicating isotherms in the stratosphere, 15-micron channel, Tiros VIII. Stratospheric temperature, OK. January 9–15, 1964.

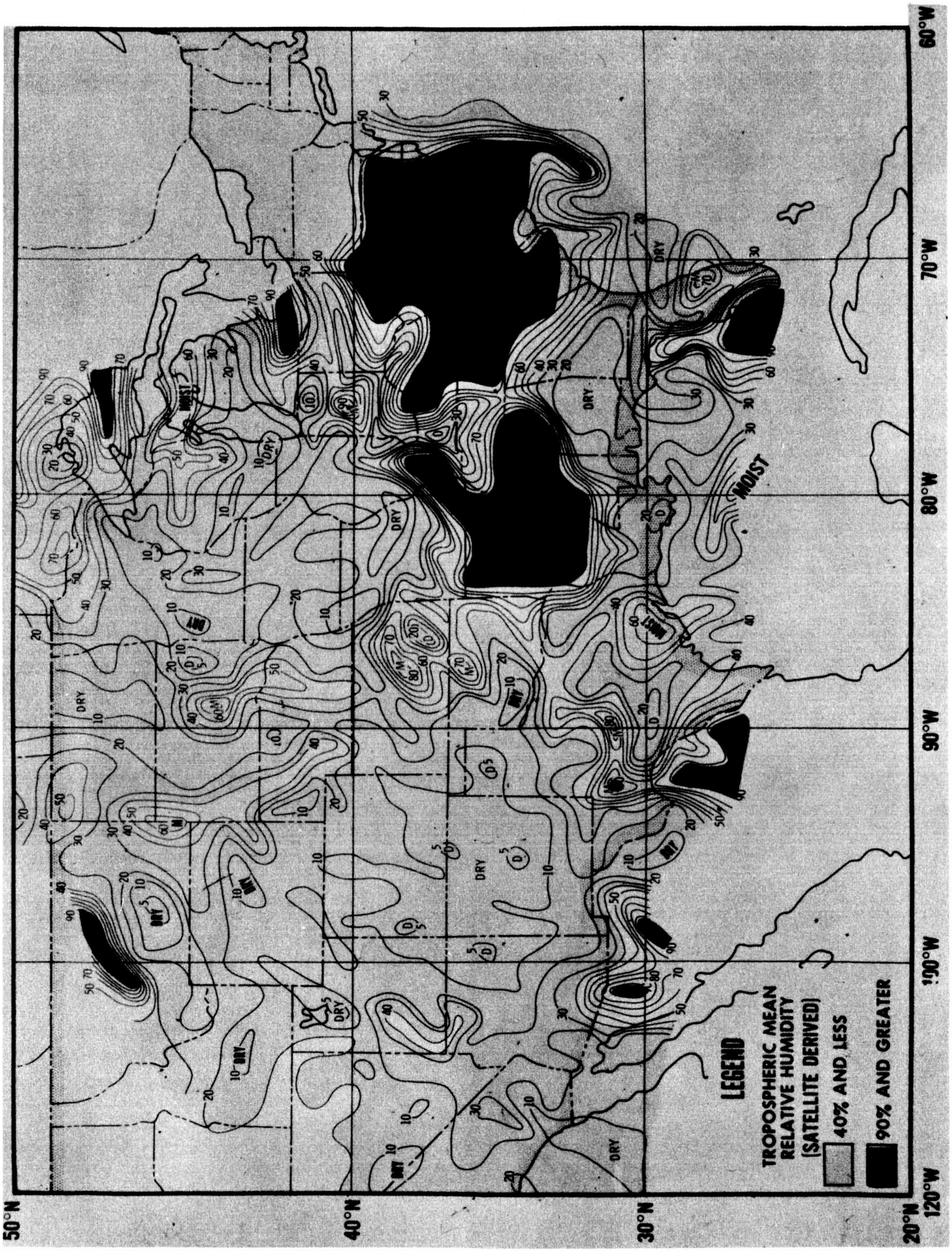

FIGURE 16.—Tropospheric relative humidities over the United States.

States. This picture was received by the APT station at Pacific Missile Range, Calif.

A specific example of the usefulness of APT in a "prognostic" sense was a photograph* obtained on orbit 1150, March 9, 1964, at 17:58:21Z. This photograph was instrumental in developing a FAWS forecast (FT–2), on the basis of discussion of the implication of the field with the FAWS forecaster which was at considerable variance with the previous FT–2. The FT–2's issued at 1700Z on the 9th and 2308Z on the 9th were compared.

Specifically, the 1700Z FT–2 of the 9th was prepared prior to the acquisition of the photograph and indicated a cold front passage at JFK International Airport with considerable thunderstorm activity and generally improving conditions after 1500Z on the 10th. This was based on a surface analysis which carried a warm front to the west of JFK and a cold front farther to the west. The implication being that

*Unfortunately no copy is available for inclusion in this paper.

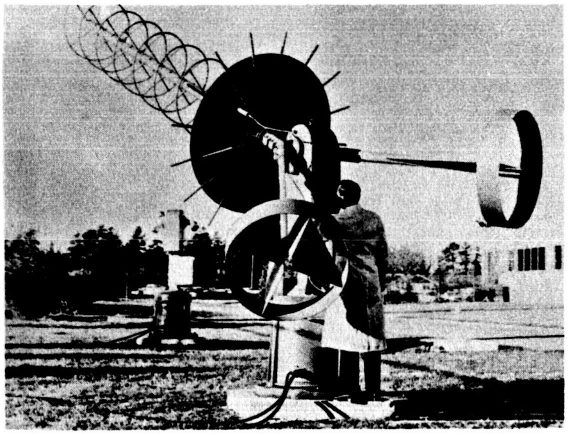

FIGURE 17.—One type of ground station antenna being used by APT reception.

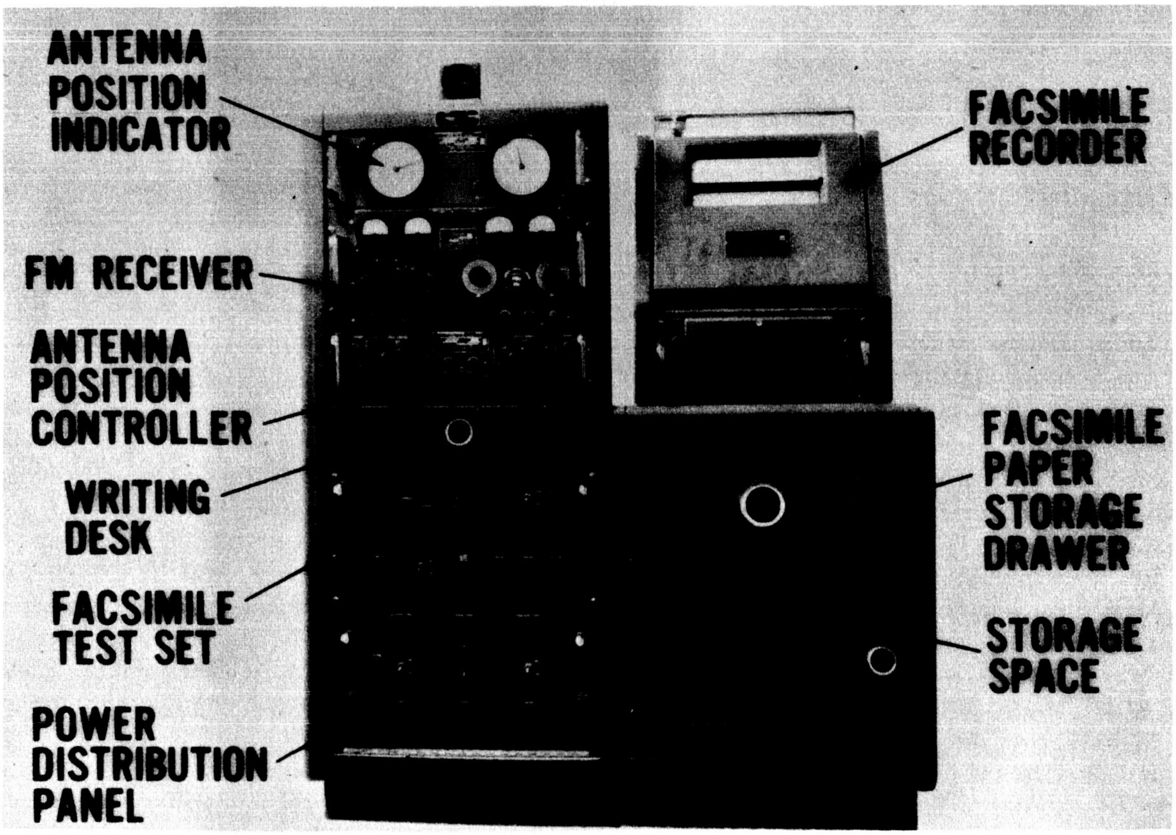

FIGURE 18.—APT ground station console.

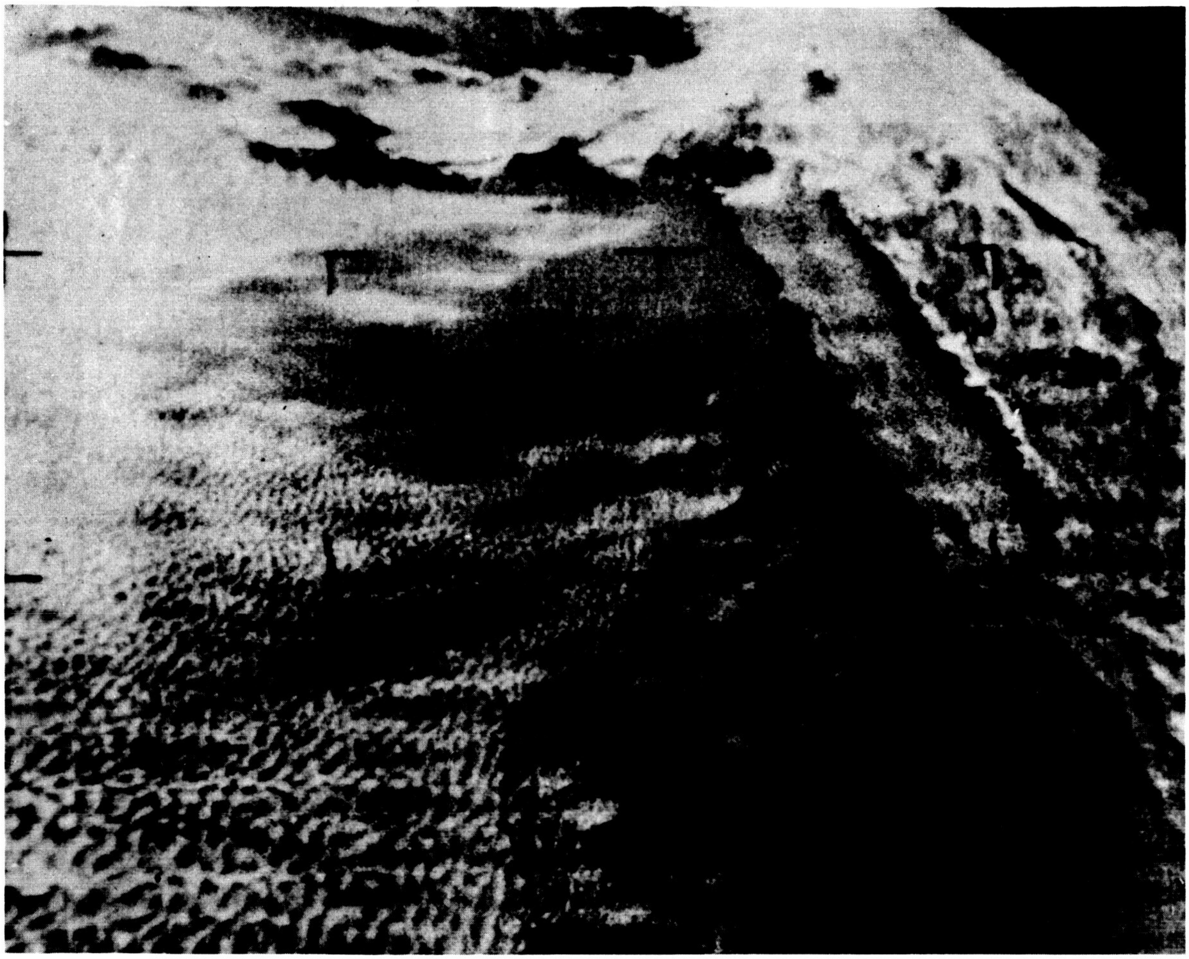

FIGURE 19.—An APT photograph from Tiros VIII, showing the west coast of the United States.

a warm front passage at JFK would be followed by a cold front passage later on. In other words, JFK would have gotten into the warm sector.

The photograph indicated that the main front was an east-west affair located well south of JFK and that what was being carried as a cold front to the west was really, in effect, an occlusion undergoing frontolysis. There was no well-defined system of cloud to indicate a front to the west, but rather a uniform cloud mass with no apparent light or dark areas. The absence of light areas implied the absence of cumulo-nimbus activity in the area to the west. Discussion with the FAWS forecaster then resulted in a reanalysis of the frontal structure and a consequent change in the FT–2. The FT–2 issued at 2308Z on the 9th deleted the FROPA and thunderstorm activity (that was in the previous FT–2) and improved the weather immediately, for a time, and deteriorated it again after 0700Z on the 10th, more or less a reversal of the previous FT–2. This revision worked out quite well. It is not meant to imply that the forecast might not have evolved in the same fashion when all the conventional data were examined for the period prior to 2300Z. However, the photograph was available, and discussion of its implication was made at about 1900Z. This started the revision in thinking, and a study of subsequent conventional data did bear out the interpretation resulting in the new FT–2. In other words, the photograph was definitely an input which, when combined with later conventional data, produced good results.

The Present Program

In the next 18 months to 2 years, we are planning to do two things:

(a) Complete the qualification of the second-generation meteorological spacecraft system, Nimbus, and launch the spacecraft.

(b) Adapt and convert the Tiros and Nimbus technology to an operational system capable of meeting the national weather service's minimum operational requirements.

NASA is undertaking both these tasks with every expectation of success.

Nimbus

The Tiros system has served the Nation well, but even before Tiros I was launched on April 1, 1960, we recognized that it was a device of limited capabilities that would ultimately be replaced. Bolstered by our early success with Tiros we took a "giant step" forward. We replaced the spinning 300-pound spacecraft, Tiros, with only 20 watts of power and carrying only 70 pounds of sensors, by the 800-pound earth-oriented Nimbus, with 200 watts of power and capable of carrying at least 250 pounds of sensors and of staying in a polar orbit. Figure 20 is an artist's drawing of the Nimbus spacecraft in flight. The developmental step between Tiros and Nimbus is well illustrated by the artist's sketch of the two systems in figure 21. The Tiros spacecraft photographs about one-seventh of the Earth every day with a resolution of about 3 miles. Nimbus will take a picture of every one-half square mile of the Earth once a day.

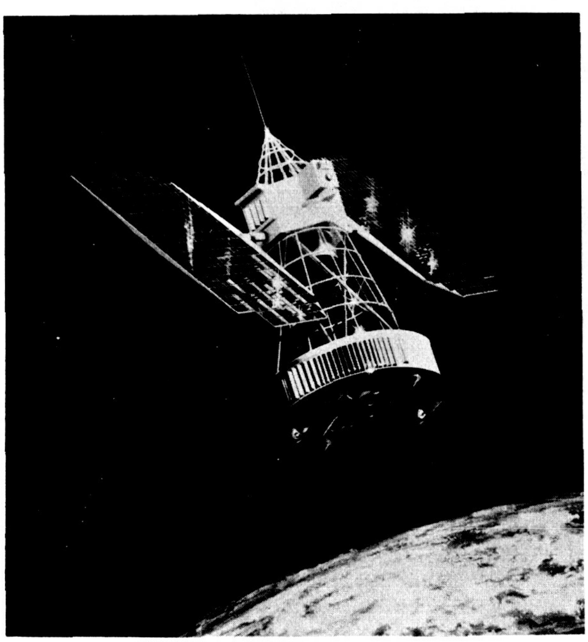

FIGURE 20.—The Nimbus spacecraft.

The Nimbus spacecraft will also carry infrared equipment for high-resolution measurements of the nighttime clouds, a feat not possible with present TV systems. An APT system using the existing ground complex of stations will be in operation. Follow-on flights will see the inclusion of advanced five-channel radiometers like the Tiros unit, for mapping clouds and cloud heights, water-vapor distribution, stratospheric temperatures and so on. Interferometers, high-resolution spectrometers, passive microwave equipment, and other atmospheric sensors will be tried.

Nimbus is absolutely *essential* to the national weather satellite program for one fundamental reason. The meteorologist in forecasting the weather—and the ultimate use of the meteorological satellite is as an operational tool supporting the weather services—uses the wind and pressure fields as his principal data inputs. Today, the satellite cannot measure these parameters either directly or indirectly. However, the meteorological satellite can and does make physically significant measurements; and we in the atmospheric sciences must learn the language the satellite speaks. Nimbus has the power, stability, and other properties required for this learning process.

The Tiros Operational System

At the request of the national weather services and with the funding of the Department of Commerce—U.S. Weather Bureau, NASA has undertaken the task of converting the Tiros technology—developed with NASA funds—to an operational system capable of meeting the minimum operational requirements. Briefly stated, these requirements are for cloud photographs of the entire Earth at least once each day. The global coverage is to be delivered by the satellite to a central processing facility; in addition, local readout of the pictures (APT) is required.

The ordinary spin-stabilized Tiros cannot provide global coverage efficiently. One of NASA's biggest contractors in the meteorological satellite area has devised a scheme which will solve the global coverage problem, and, in addition, provide more readily handled picture data. Figure 22 illustrates how a Tiros satellite, still spin-stabilized but now turned so that the spin axis is always perpendicular to the plane of the orbit, can provide global coverage. The camera, whether

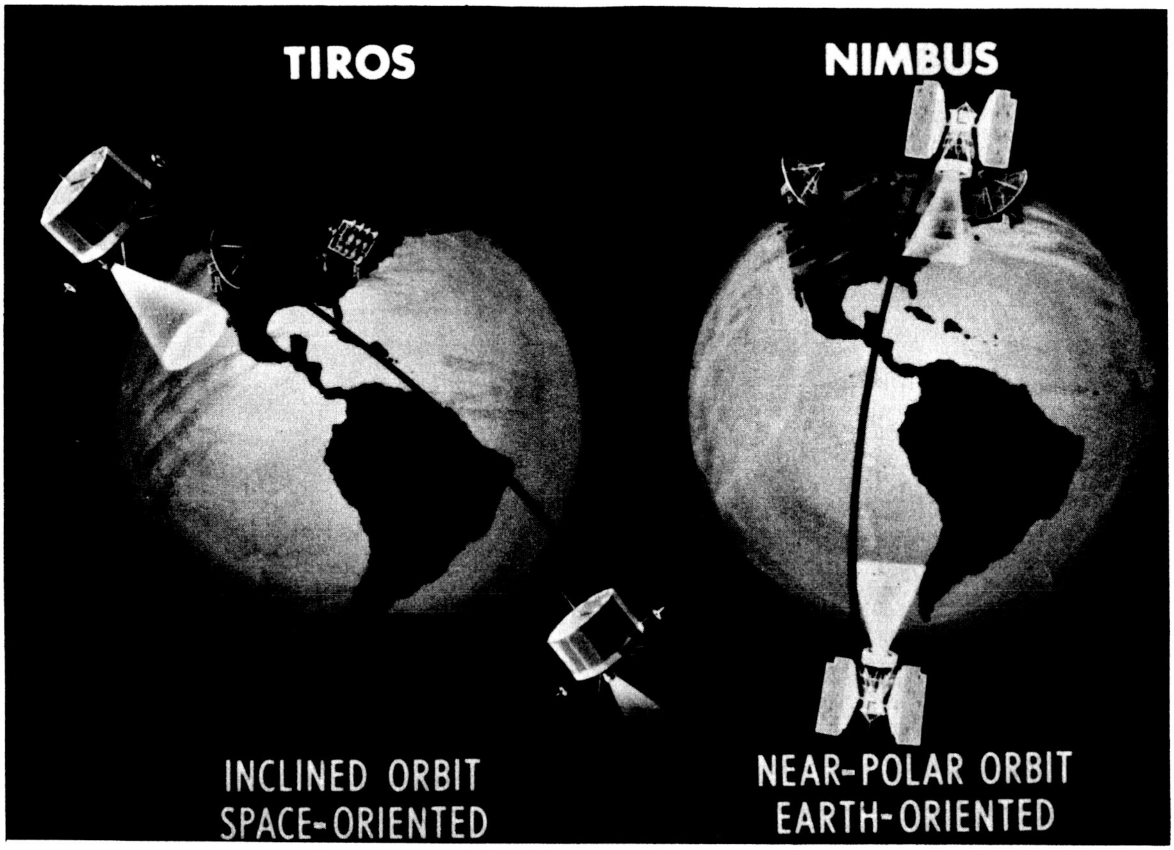

FIGURE 21.—Meteorological satellite development: Tiros and Nimbus.

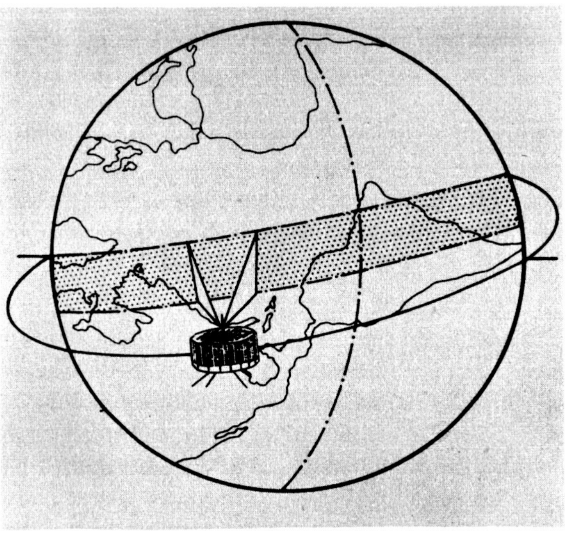

FIGURE 22.—A sketch illustrating how a Tiros satellite can provide global coverage.

a conventional vidicon or the APT system, looks outward from the side of the spacecraft. The shutter of the camera is triggered by the horizons of the Earth so that the picture is taken when the camera points straight downward.

The next Tiros launched, Tiros I, will be in this *cartwheel* configuration. This R&D unit (which has been funded by NASA) will prove the concept and the hardware and make possible the minimum operational system we are calling the Tiros operational system (TOS). It is planned now to prepare two basic cartwheel spacecraft: one will contain two APT cameras of the type developed for Nimbus for local readout and the other will contain two of the advanced vidicon cameras also developed for Nimbus. The spacecraft are identical except for the cameras. The use of two cameras in each spacecraft is indicative of the redundancy being used in the Tiros system. It is an improvement over the previous Tiros systems

in the degree of "cross-strapping" of subsystems. Thus, the failure of one of the two tape recorders will not destroy the satellite usefulness, because the backup unit can be used with either vidicon or either transmitter. The same is true of other major subsystems of the spacecraft.

To be economically feasible, an operating system must have a predictable, reasonably long life. Obviously, the longer the life, the lower the annual operating costs of the system. The facts, that (1) the Tiros hardware has proved its life capabilities (Tiros VI lasted 13 months and Tiros VII will be 1 year old in June) and that (2) better use is being made of redundancy, give us confidence that an economically acceptable system can be brought into being.

THE FUTURE

We cannot produce a crystal ball at this point, but there are some important questions to be answered, some problems to be solved, and some hardware to be developed before the national and world weather services can make the most effective and economical use of this new aerospace tool. Figure 23 is an illustration of the lifetimes of typical weather systems, one of the most serious problems. This problem is characteristic of any measurement made on the weather system; only the clouds are illustrated here. A periodic measurement is being made of a power spectrum, or, more simply put, if the storm lasts only 3 hours, and Nimbus or Tiros makes a measurement every 24 hours, it is obvious that the satellite might not even see the storm. One solution, and probably the most effective, will be to place a satellite at synchronous altitudes. Then the sensor system can look down on the same area of the Earth and keep it under constant observation.

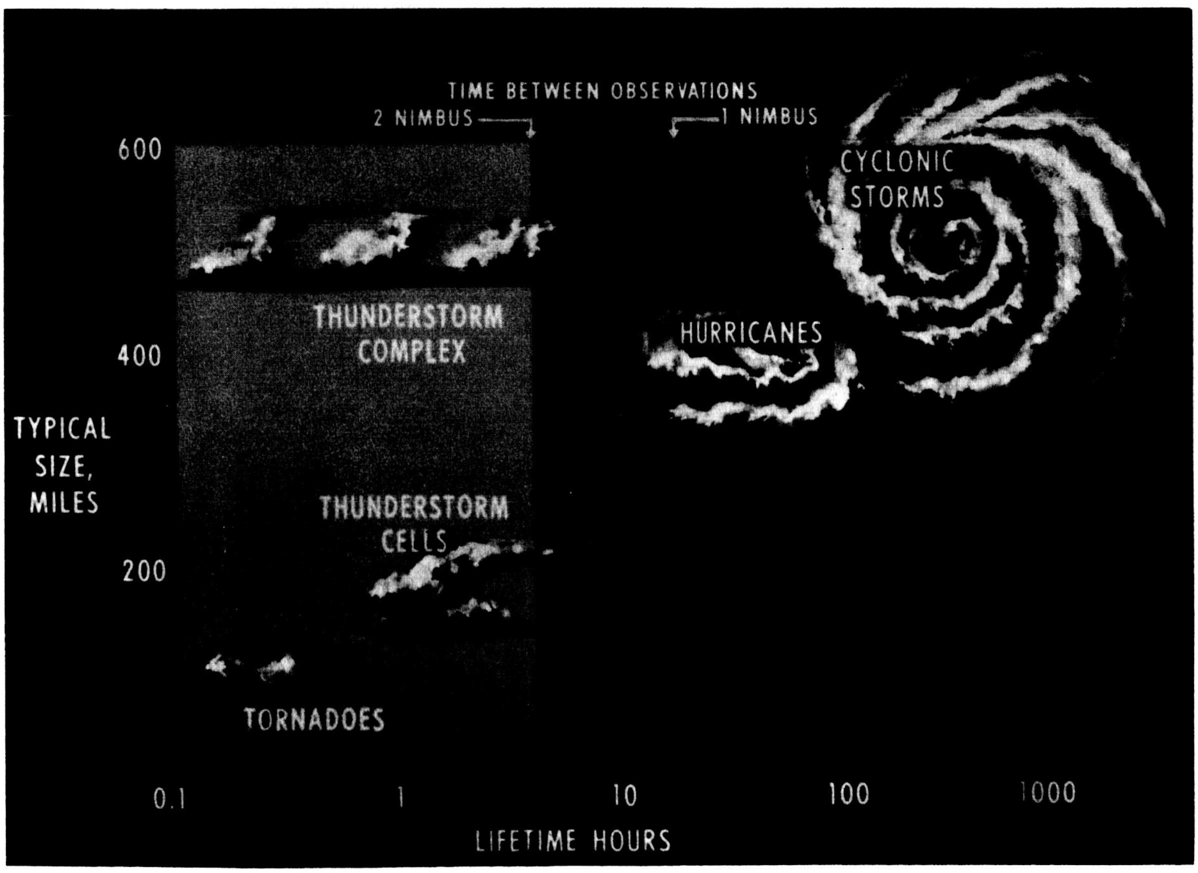

FIGURE 23.—Lifetimes of typical weather systems.

Aside from the more fundamental questions already mentioned (that of learning to "speak the language"), we are faced with the task of making nighttime cloud cover measurements, of measuring the pressure and wind fields, of developing reliable, predictable-life systems, and of finding techniques for handling 100 to 500 million bits of data in real time—to mention just a few.

CONCLUSION

In the meteorological satellite area, the nation has embarked on a program that promises to be of great benefit and service to all mankind. It will save lives and property and, in time, make the lives of each of us just a little bit fuller and more enjoyable.

It may be that the meteorological satellite program is the best example of the peaceful use of space.

N64-30342

COMMUNICATIONS SATELLITE TECHNOLOGY

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One of the first applications of Earth-orbiting satellites considered was for intercontinental communications. Neither of the other means available—cables and high-frequency radio—completely meets the current requirements of intercontinental communications. A modern system must be capable of furnishing real-time contact between any two points on the Earth whenever the user or customer wants it. It must be reliable and it must be flexible. Cables are reliable but have fixed end points and, therefore, lack flexibility and require a high density of traffic between these points to justify their installation. High-frequency radio, on the other hand, has the requisite flexibility and can provide communication between any two points having the necessary local fixed equipment; but it leaves much to be desired in reliability. It depends on the ionosphere acting as a reflector to direct the signals over the horizon, and the user is left at the mercy of a highly variable transmission path.

Earth-orbiting satellites have, potentially at least, the answers to the shortcomings of both cables and high-frequency radio while still meeting the other requirements of intercontinental communications. Frequencies high enough to be independent of the ionosphere can be used to provide the high reliability without sacrificing the flexibility of high-frequency radio.

There were, however, a number of problems to be solved before such a system could be considered practical from an operations viewpoint. A communications satellite system has been compared with a microwave relay system, and the similarities have been stressed. From the engineer's viewpoint, however, the differences are much more substantial. The distance between transmitter and receiver is much greater; the repeater must operate in an environment quite different from that on the Earth's surface, one that even now is not completely defined; the power available at the repeater is severely limited; the entire package must survive launching and then operate for a long period without servicing or attention of any kind. These were very serious problems when the communications satellite program was undertaken in NASA. The story of their solutions and the development of the technology to the point where it can be turned over to the industry for use in routine communications service is interesting and one in which all of the scientific community who took part can take pride.

COMMUNICATIONS SATELLITE SYSTEMS

A communications satellite cannot be considered apart from the system in which it operates. The design of the satellite must consider the nature of the signals that will pass through it. The location, movement, and power output of the satellite determine the specifications for a suitable ground station to operate with it. It is not surprising, therefore, to find that development of ground-station technology has proceeded concurrently with the development of the satellite.

Before considering specific communications satellites, it is useful to examine the overall system to see how the satellite imposes certain constraints on the other system components and how these constraints affect the application of the system.

Two basic types of systems are shown in figure 1. The passive satellite serves to reflect or scatter the signal beamed at it from the transmitting ground station. In this respect its function is the same as that of the ionosphere in the high-frequency radio sys-

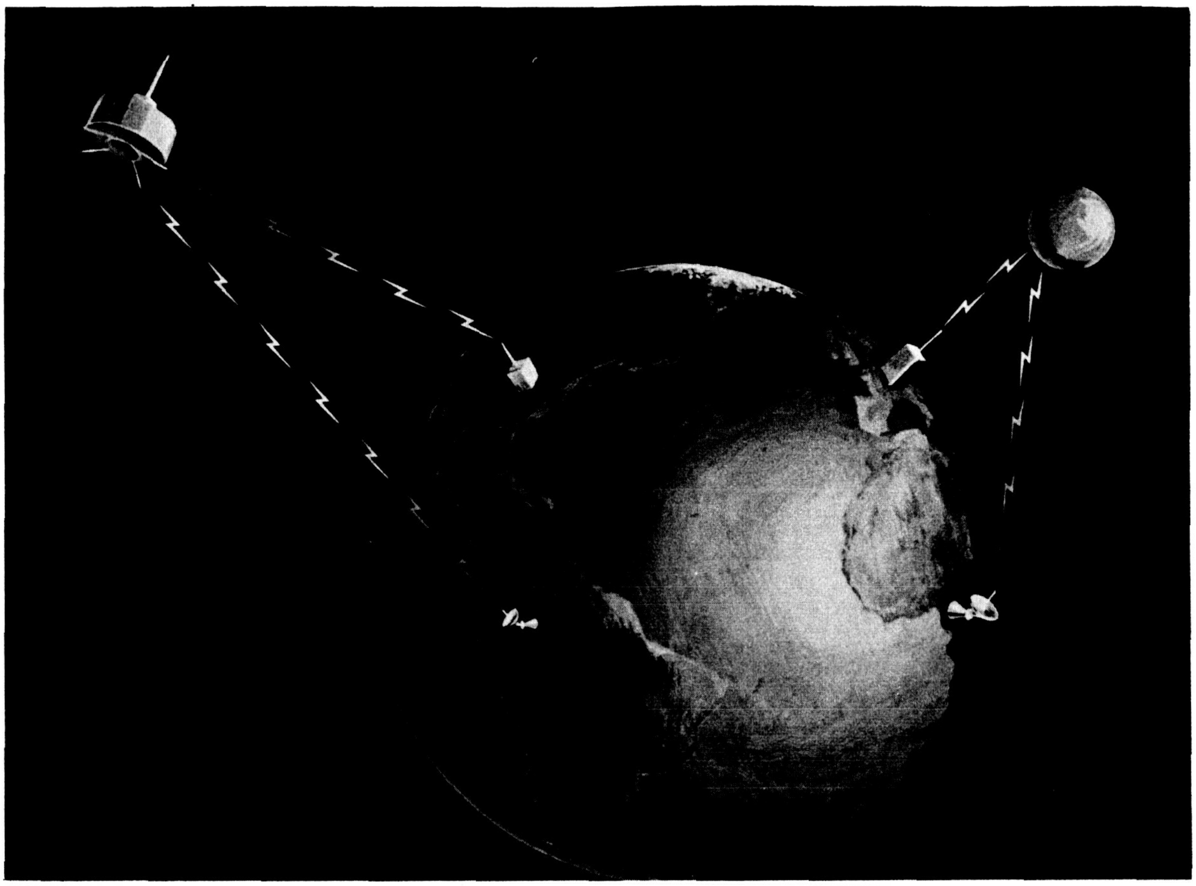

FIGURE 1.—Communications via active repeater and passive satellites.

tems. The passive satellite, however, is much more predictable than the ionosphere and, therefore, can provide a more reliable communication link. Any receiving station that can "see" the satellite can function as the other end of the link. Since the satellite will reflect signals of any frequency in essentially the same way, any two stations operating on the same frequency can communicate via the satellite without regard to any other stations using it. The only requirement is that each transmitting station operate on a different frequency. The absence of any signal amplification in the satellite results in a very low power level present at the receiver. This limits the maximum altitude at which passive satellites can be used which, in turn, limits the area on the Earth's surface from which the satellite can be seen. Thus, a large number of satellites would be required in an operational system. The high attenuation suffered by the signal means that a high power must be transmitted if the system is to have a useful capacity. The effect is to transfer complexity from the satellite to the ground station. One of the most important implications of the satellite simplicity is the long satellite limetime in orbit that can be expected. The advantages of the passive system are its potentially long lifetime, high reliability due to its simplicity, and the fact that it can be used by any number of pairs of ground stations simultaneously without interference as long as no two transmitting stations use the same frequency. The advantages appear at the present time to be more than outweighed by the disadvantages if commercial use is considered. The primary disadvantage is the requirement of complex and, therefore, expensive ground stations for even a limited traffic capacity. The development of larger satellites in the future may make them attractive in some kinds of service.

The other system shown in figure 1 is the active

communications satellite system. This system differs from the passive system in that the satellite, after receiving the signal from the transmitting ground station, amplifies it and retransmits it at a much higher power level. This feature allows much simpler ground stations to be used for a given traffic handling capability than is necessary with a passive system. It also requires a much more complicated satellite than the balloon of the passive system, and it can be used simultaneously by only a limited number of ground stations. Since there is a much higher power level on the down link than there is with a passive system, the satellite can be placed at a much higher altitude and can, therefore, provide wider geographical coverage.

Having briefly described the two main classes of communications satellites in a general way, let us now consider the present state of the technology.

REVIEW OF PRESENT TECHNOLOGY

Passive Satellites

On August 12, 1960, the first passive communications satellite, Echo I, was launched by NASA. Almost 4 years later it is still orbiting the Earth and is being used in communications experiments. It was originally in the shape of a sphere with a diameter of 100 feet and was made of Mylar film which was made reflective by a very thin layer of evaporated aluminum. The effects of solar pressure and the tendency of the material to refold after internal pressure was lost has caused it to lose its spherical shape and greatly reduced its effectiveness as a communications device.

Echo II was launched in January of this year and represents an improvement over Echo I in size and rigidity. Echo II is 135 feet in diameter; this results in a twofold increase in signal level at the receiving station, all other factors being constant. It is constructed of a material made by laminating two thin sheets of aluminum on each side of a Mylar sheet. When this material is stressed sufficiently, it is smoothed out and loses its tendency to refold. It then is rigid enough to resist the force of solar pressure which would deform it. It can, therefore, be expected to remain useful as a communications satellite much longer than did Echo I. Figure 2 shows one of the test spheres inflated in a hangar at Lakehurst, N.J., prior to the launch. Techniques for handling large structures of this type and for making quantitative measurements of the surface characteristics, both optically and electromagnetically, were developed. The development of the Echo II satellite has resulted in the development of materials, processes, and techniques with potential applications in other than communications satellite technology. It makes available techniques for erecting large structures in space, such as directive antennas and large solar collectors. Means for controlling the inflation of such structures by the use of subliming solids were demonstrated. A television system was carried in the Agena vehicle and was used to view the deployment and inflation in space of the Echo II sphere in real time.

The versatility of the passive system is dramatically demonstrated by Echo II. The U.S. Air Force is conducting experiments with Echo II using their facilities at Rome, N.Y., Trinidad, and Ohio State University. The U.S. Navy and NASA are engaged in a cooperative program, using facilities of the Naval Research Laboratory at Stump Neck, Md.; the Naval Electronics Laboratory at San Diego, Calif.; and the Collins Radio Co. at Dallas, Tex. The United Kingdom and the U.S.S.R. have conducted experiments between the Jodrell Bank Observatory in England and the Zimenki Observatory at Gorkiy, Russia. The U.S. Coast and Geodetic Survey has indicated an interest in using it in survey work. All of this has been done without the necessity of scheduling the availability of the satellite to those who desire to use it. NASA has freely supplied orbital information to any who desire it to allow them to track the satellite.

Echo I and Echo II have also provided visible evidence to the entire world of our ability to orbit manmade satellites. This can be expected to spark the imagination of young people particularly and create an interest in the space program.

Active Satellites

Active communications satellite technology has advanced to the point where a corporation has been chartered to establish and operate a system utilizing satellites for international communications. The technology has been demonstrated by the successful launching by NASA and experimental use of five active communications satellites. On July 10, 1962, NASA launched the first Telstar satellite for AT & T. This was followed on December 13, 1962, by the launching of Relay I, which is still operating and is being used in experiments and demonstrations between the United States and Europe, South America,

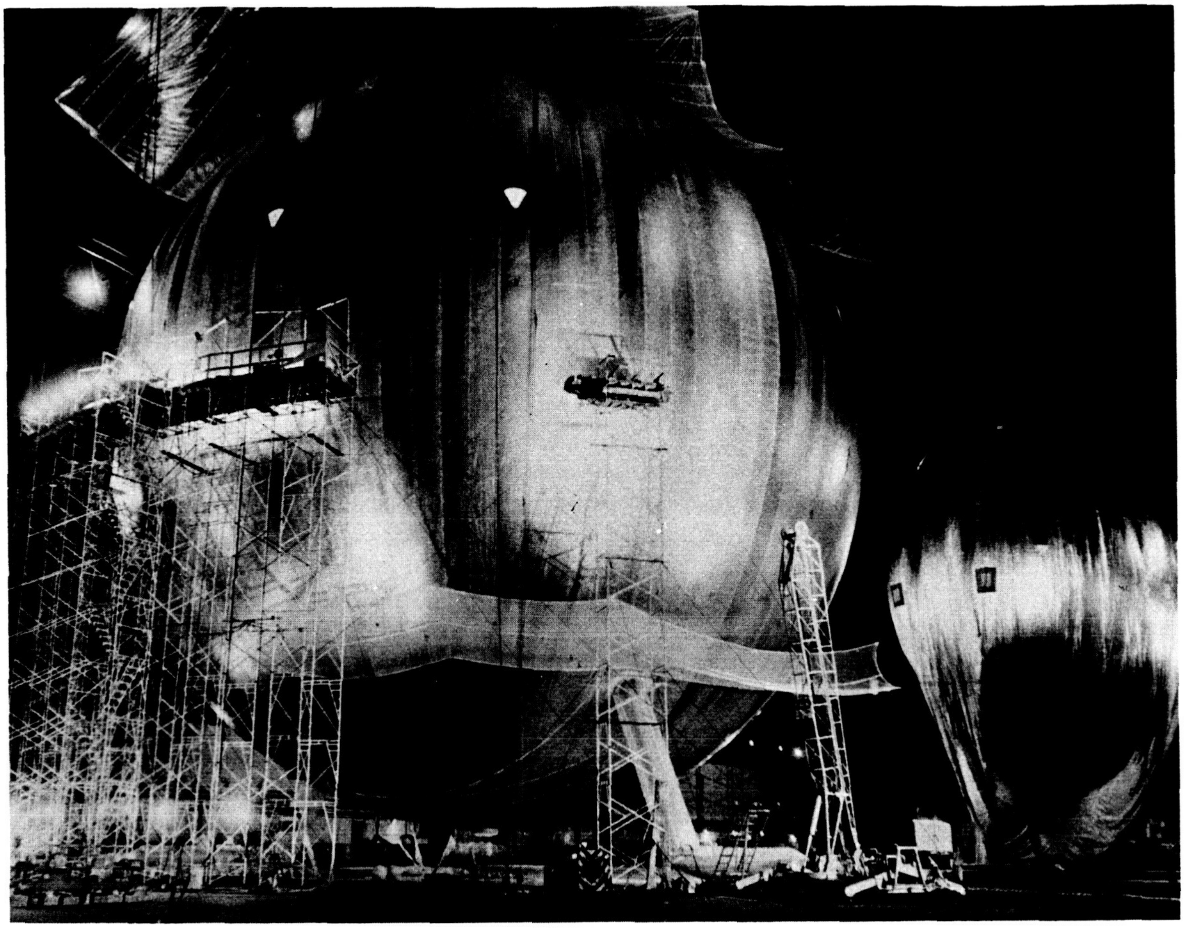

FIGURE 2.—Echo II test sphere.

and Japan. 1963 saw the successful launching of the second Telstar and Syncom. In January of this year the second Relay satellite was launched. Of these five satellites, all but the first Telstar are still operating and furnishing valuable information for future planning and satellite design.

The most difficult problem facing the designers of the first active communications satellites was how to make a satellite with a lifetime of at least 1 year in orbit. A lifetime of 1 year was chosen as a goal not because this would provide an economical system but because, considering the state of the art at the time and past experience, this seemed to be almost impossible. However, subsequent experience has shown even longer lifetimes to be feasible at the present time.

The only part of the spacecraft with an inherently short life is the power-supply system. All other subsystems could be expected to survive for a very long time in space, barring any unexpected severe environmental conditions in space, if they survived the rigors of the launch. The knowledge of the space environment was based on somewhat scattered data points and involved some extrapolation to get to the conditions to be expected. A high-altitude nuclear test a short time prior to the launching of the first Telstar resulted in an enhanced radiation field through which the satellite traveled. This is thought to have contributed significantly to the premature failure of the command system of this spacecraft and has increased the rate of degradation of the solar cells used to supply power to subsequent satellites in the medium-altitude range.

This first Relay satellite was launched by NASA on December 13, 1962. The satellite is shown in figure 3. Characteristics of the orbit and the satellite are shown in table I.

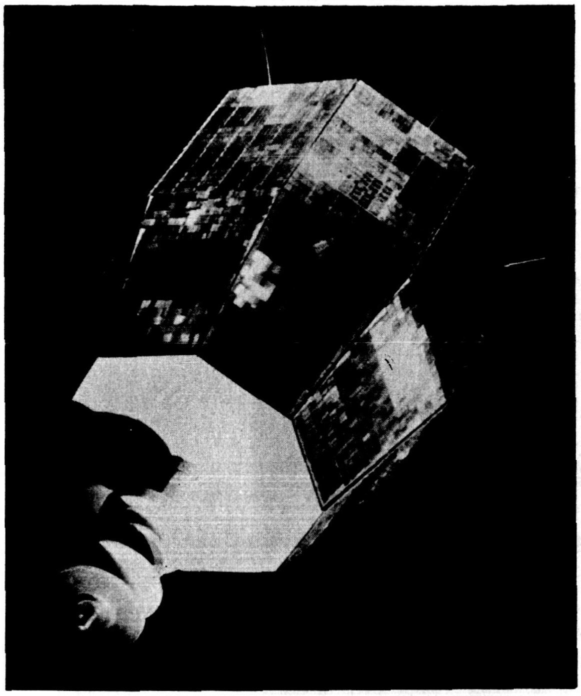

FIGURE 3.—The first Relay satellite.

TABLE I.—*Relay I orbit and satellite data.*

Spacecraft weight	172 pounds
Height of apogee (approx.)	4,000 nautical miles
Height of perigee (approx.)	700 nautical miles
Inclination	47.52 degrees
Stabilization	Spin
Communications frequencies:	
Up link	1,725 Mc
Down link	4,170 Mc
Modulation	FM on both up and down links

Figure 4 shows the Relay satellite in orbit. Relay I is spin-stabilized with the spin axis in the plane of the orbit. The antenna pattern, shown in figure 4, is a figure of revolution about the spin axis. The satellite is useful for communications use only when in the orientation with respect to the Earth as shown. Twice in each orbit one end of the satellite is pointed toward the Earth, and the Earth is in a null of the antenna. In this orientation the satellite is not used. The orbit has an apogee of approximately 4,000 nautical miles and a perigee of approximately 700 nautical miles. This orbit was chosen because it provided mutual visibility times between North America and Europe of up to about 50 minutes when apogee occurred over the North Atlantic. This was important to allow meaningful experiments and convincing demonstrations to be performed between the AT & T. ground station at Andover, Maine, and the British and French stations at Goonhilly and Plemeur Bodou, respectively. In addition to communications between these large stations, smaller stations in the United States, South America, Italy, and Japan successfully communicated via Relay. The ground stations that participated in the Relay experiment are shown in figure 5.

A significant part of the project staff's efforts has been devoted to scheduling the use of Relay I by the large number of ground stations desiring to use it. The procedures that have been developed are considered to be a major contribution of the project to communications satellite technology.

The central point of the Relay system is the operations control office at Goddard Space Flight Center, Greenbelt, Md. This office, designated COMSOC for Communication Satellite Operations Center, is used to direct all command and control of the satellite, evaluation of real-time data, and as the office through which all communications experiment scheduling and coordination is conducted. COMSOC issues all operation plans and experiment schedules and acts as a clearinghouse for orbital predictions and correlated data.

The Relay satellites are operated daily. Because of the size limitations on the power supply and since the wideband subsystem represents a severe electrical load, it is necessary to exercise precise control in order to realize maximum utilization of available power. This can only be effected through the means of reliable command capability and real-time telemetry data readout. The spacecraft is controlled by COMSOC, utilizing the test station (COMCON) to provide the command and telemetry function at the direction of COMSOC. These functions are critical because of the necessity for turning on the spacecraft at a prescheduled time in order that one or more communication stations can conduct experiments. The actual control of the satellite is performed by the COMSOC-COMCON combination with direction being supplied by COMSOC.

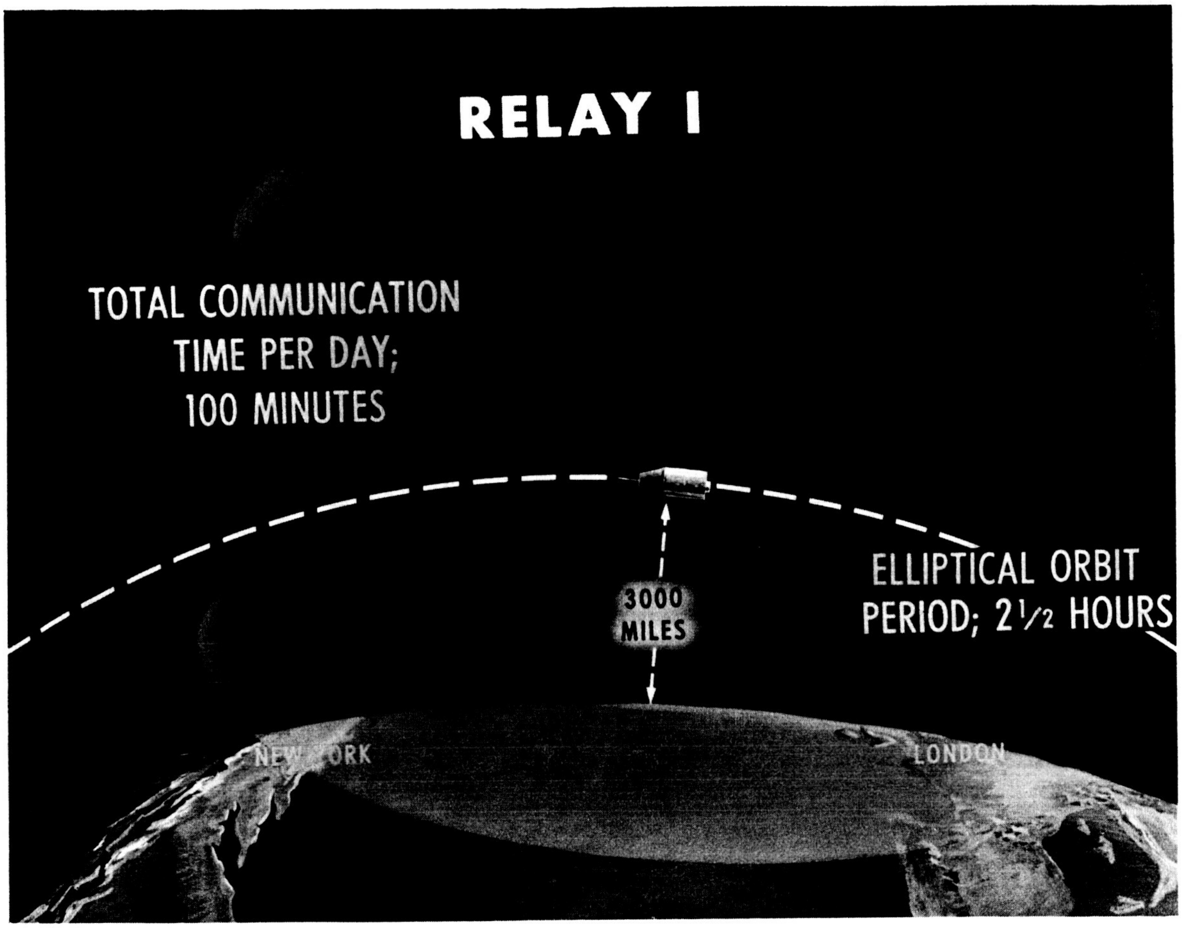

FIGURE 4.—Relay I in orbit.

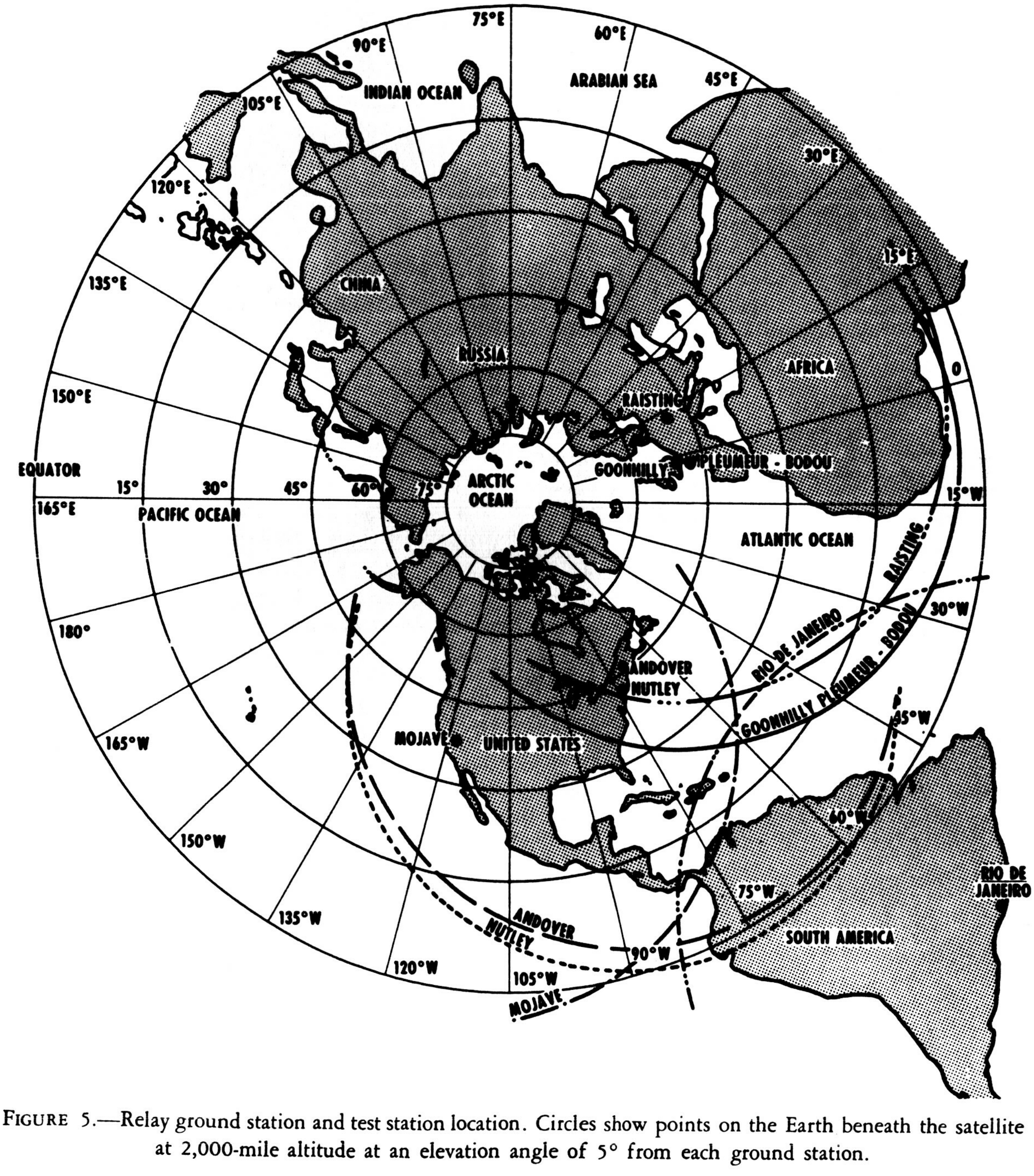

FIGURE 5.—Relay ground station and test station location. Circles show points on the Earth beneath the satellite at 2,000-mile altitude at an elevation angle of 5° from each ground station.

Controlling the experimentation on Relay is a continuous problem because each station has a diversified capability unique to itself. In addition, the variety of communications experiments to be conducted are complex. They require coordination so that the stations participating are assured of adequate test setup time. Of course, one aspect not to be neglected is that Relay has the capability of supporting public demonstrations of television, teletype, facsimile, and telephony. To make certain that these demonstrations are started at the precise time that the transponder is available, COMSOC has been used to cue the program network. Many of the requirements of the Relay system are the result of the experimental nature of the program. Some of the requirements, however, are common to both experimental and operational systems. Therefore, the experience gained with the Relay satellites should be of value in establishing an operational system.

Control of the spacecraft is exercised from either of the stations at Nutley, N.J. (fig. 6), or Mojave, Calif., under direction from the Goddard Space Flight Center; and it is necessary for them to determine the spacecraft condition at the beginning of each pass during which it is to be used before releasing it for an experiment or a demonstration. This prevents possible damage to the spacecraft which could be caused by operating it in certain conditions. It also serves to insure that experiments will be meaningful and that the user will not be embarrassed by using the spacecraft in a demonstration when it is in a substandard condition.

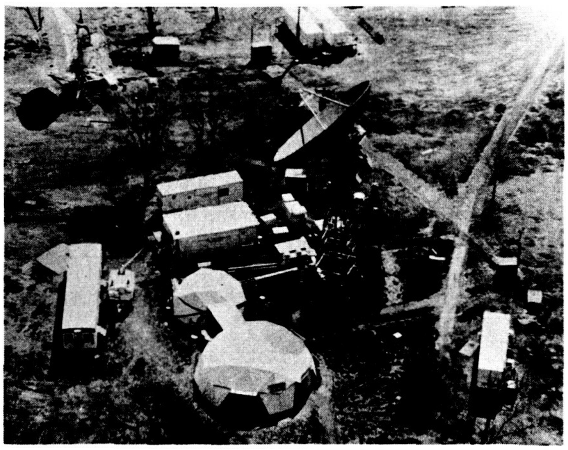

FIGURE 6.—Station at Nutley, New Jersey.

Figure 7 shows a block diagram of the telemetry system in the satellite and at the test station. After reception at the test station the data are processed and separated into three categories designated class I, class II, and class III.

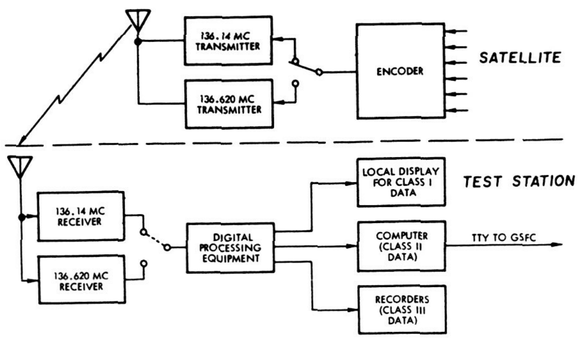

FIGURE 7.—Relay telemetry system.

Class I data are reduced in real time and may be used for making a GO/NO–GO-spacecraft-operation decision. There are nine such items of information. A digital limit checker compares the incoming signal values against preset limits. If all critical values are within tolerance, a row of green lights appear. If a signal is out of specification, a red light appears and an alarm is sounded. Since the lights are labeled, the operator can tell immediately which parameter is faulty. The class I data are also recorded in analog form on a paper strip recorder.

Class II data consist of 34 items of spacecraft telemetry and are utilized to determine spacecraft condition in more detail than is available from class I data. Class II data are also reduced in real time, formatted for transmission over a teletype circuit, and transmitted to Goddard Space Flight Center in order that the detailed status of the spacecraft can be observed immediately prior to, during, and following utilization of the spacecraft.

Class III data contain all of the class I and II and radiation experiment telemetry data. Class III data are recorded on magnetic type for future data reduction. The tape recorder also records digital time for proper time tagging of events. Recording tapes are sent to the Data Reduction Center at Goddard.

Figure 8 is a block program illustrating the flow of information in controlling and scheduling the satellite.

The Project Relay satellites have performed very

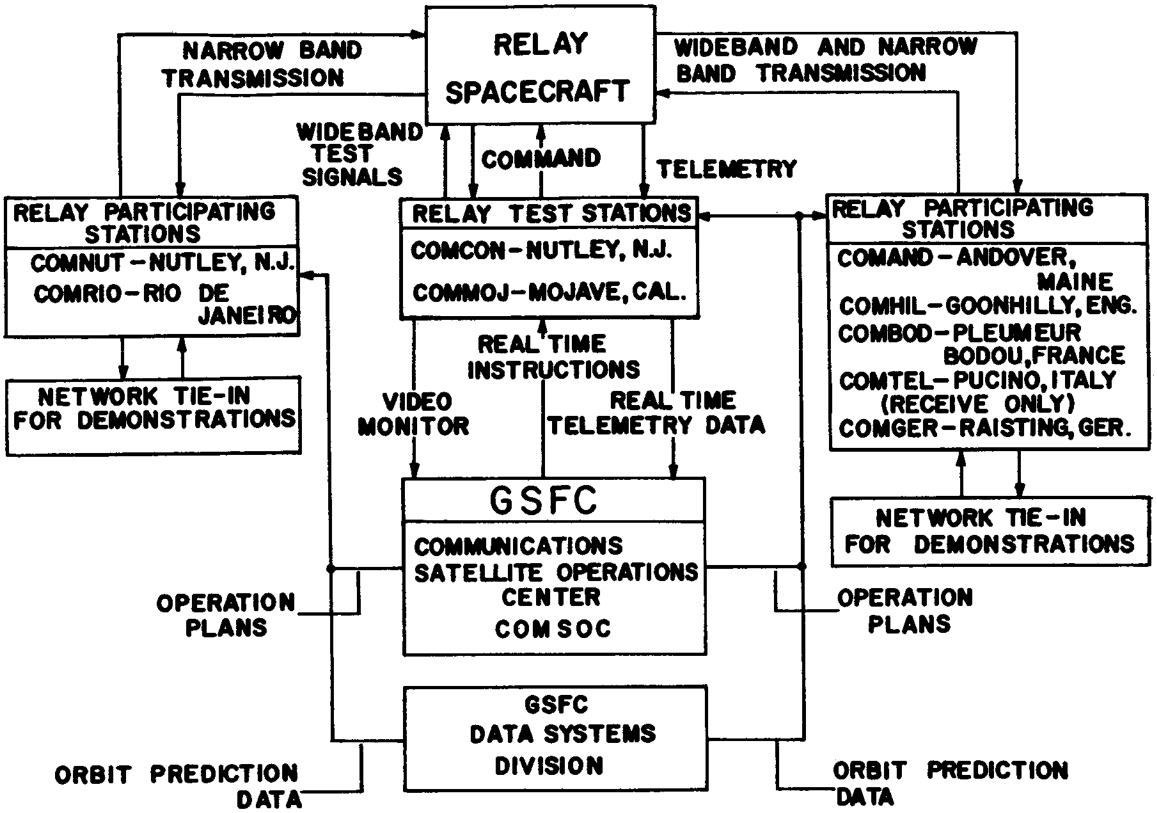

FIGURE 8.—Relay operations control system.

well as a communications medium. The large number of experiments conducted by all the participating stations validated the original system design philosophy and the choice of operating parameters. The fact that the repeater is a moving vehicle in a space environment has presented no particular difficulties not encountered with a ground microwave relay system.

The communication system in the Relay satellite receives the 1725 Mc transmitted signal and retransmits at 4170 Mc. The system is capable of supporting one television signal or 300 one-way telephone channels at a time. The satellite can be switched to a narrowband mode which can provide 12 simultaneous two-way channels. As of April 8, 1964, the Relay I spacecraft has been used for 1,372 wideband experiments, 653 narrowband experiments, and 172 demonstrations; and the transponder had been operated for 302 hours during 760 operations. In addition, there has been much radiation data taken. The general results of the communications experiments are summarized below.

The Relay system test categories are as follows:

- Wideband (television and 300-channel telephony)
  - Received carrier power
  - Noise—random, periodic, and impulsive
  - Linear distortion
    - Waveform tests
    - Steady-state characteristics
  - Nonlinear distortion
    - Differential gain and phase
    - Differential time delay
    - Intermodulation noise
  - Television test signals
- Narrowband (12-channel telephony)
  - Received carrier power
  - Noise—random, periodic, and impulsive
  - Linear distortion
  - Nonlinear distortion
    - Differential time delay
    - Intermodulation—harmonic and noise loading
  - Intelligible cross talk

The wideband communication experiments consist principally of tests designed to evaluate the Relay system with respect to its ability to transmit a television picture and sound. However, two of the experiments are directly related to the transmission of frequency-division multiplex (FDM) telephony by means of frequency-modulated (FM) carrier. The wideband mode of the satellite was designed to accommodate 300 FDM/FM telephone channels in half-duplex (one-way) operation. The narrowband communication experiments are designed to evaluate the ability of the system to transmit 12 two-way FDM/FM voice channels. In addition to voice transmission, these telephone channels can handle several frequency-shift keyed (FSK) teletype channels or facsimile. A number of public demonstrations also have been conducted using the telephone and television capabilities. The communication performance of the Relay communication satellite system can be conveniently summarized in the framework of the experiment categories shown above.

In the thermal-noise-limited Relay system, adequate received carrier power is essential. Generally, fair agreement between predicted and measured carrier power has been obtained. Nevertheless, it is not unusual to observe discrepancies of several decibels during a typical pass. A system margin of 5 to 6 db to provide for such occurrences therefore seems mandatory in future system design. Because of the vanishing margins at the smaller stations, difficulty in making some of the communication tests has been encountered. Phase-lock demodulators have been utilized and proved their worth in lowering the minimum received signal power required. Without them, additional spacecraft with effective radiated power or lower noise ground stations with greater antenna gain would be necessary. Operation near threshold has been hampered by the modulation on the carrier because of the spin of the satellite. Spin modulation has also caused some difficulty in autotracking for some stations when at high-elevation angles.

Agreement between predicted and measured post-detection signal-to-noise ratios has been in most cases less satisfactory than for received carrier power. This is primarily due to the difficulty in predicting the characteristics of the baseband noise and its effect on the signal at low levels.

Linear waveform and steady-state response tests have indicated that the satellite contributes slightly to linear distortion. This was expected. Linear distortion is principally a function of the baseband equipment. Since this equipment is not substantially different from that which would be used in a ground microwave relay, except for greater deviations and bandwidths, the design considerations and problems should be similar.

Substantial nonlinear distortion, on the other hand, has been discovered both in the ground equipment and the satellite. Differential gain measurements have shown the baseband equipment to be relatively free of nonlinear distortion. Differential phase and differential time delay, however, exist both in the ground and satellite IF and/or RF equipment. The differential phase was found to be excessive for the transmission of quality color television, for example. However, with preemphasis and some delay equalization in the ground stations, the system could be used for color transmissions. Reasonable agreement between differential phase and delay measurements has been obtained.

The intermodulation noise in a telephone channel for the wideband mode also has been predicted from differential delay measurements and verified by noise-loading stimulation of the voice channels. In general, the intermodulation noise appears to be at or above the Relay objective, especially in the wideband mode. It would appear that some delay equalization would be appropriate. Such equalization should not be difficult to apply, since a substantial portion of the distortion appears to be located in the ground equipment.

In the narrowband mode, measurements indicate that intelligible cross talk would be a problem in a system like Relay unless complementary channel operation is employed. Complementary channel operation means that a speaker talks and listens in the same baseband frequency slot. "Intelligible cross talk" then becomes echo under these conditions. An important source of intelligible cross talk is AM-to-PM conversion in the spacecraft TWT transmitter. Cross talk could be reduced by operating this tube below saturation, but this would penalize the system by reducing the satellite power output.

The Relay project has demonstrated the feasibility of a long-life satellite and the use of this satellite in a communications link. It also, with the Telstar project, provided the inducement to other nations to develop and install ground stations for use with communications satellite systems. These ground stations now are available for use with the commercial system

to be established by the Communications Satellite Corp. The experience gained in controlling, scheduling, and operating the Relay satellite will be of great value to the corporation in establishing their system.

A satellite in an equatorial orbit with a period of 24 hours will appear to be stationery from all points on the Earth's surface from which it is visible. Such an orbit has obvious advantages when applied to communications satellites. It does, however, impose the requirements on the satellite that it be accurately controlled in orbit. A satellite in an almost synchronous orbit is visible for long periods from any particular point on the Earth but, by the same token, is invisible for long periods from those same points. The problem is further complicated by the fact that, after the orbit is adjusted to exactly the proper one, it will, in general, not remain so. This is brought about by the fact that the Earth is not perfectly spherical and its gravitational field is, therefore, somewhat distorted. The satellite must, therefore, carry means of performing orbital corrections throughout its useful life. The Syncom project was designed to investigate the problems of placing a satellite in a synchronous orbit and maintaining it there for a useful lifetime.

Syncom II, the world's first active, synchronous orbit, communications satellite, was successfully launched on July 26, 1963 from Cape Canaveral, Fla. The satellite has been adjusted to a true synchronous orbit with the orbital node at 55° W. longitude and has been oriented to place the satellite spin axis perpendicular to the orbital plane. All systems and functions of the satellite have been proven and found to be normal with only minor exceptions.

The objective of the Syncom program has been met; the feasibility of a spin-stabilized, synchronous-orbit, active-communications satellite has been demonstrated. Orbital control has been achieved without difficulty. The launch by the Thor-Delta booster and apogee motor boost resulted in the expected near-synchronous orbit. Velocity corrections and spacecraft orientation have been made by the spacecraft control subsystem in a predicted manner.

The results of communications experiments have been excellent. High-quality voice signals have been transmitted with signal-to-noise ratios up to 40 db. Photographs have been transmitted by facsimile with a resolution greater than that of standard television. The main communications ground stations have been able to lock on to the spacecraft beacon signals at elevation angles less than one-half degree.

It is predicted that satellite operation on full-duty cycles will be limited to 1 year by performance degradation of the satellite power supply. Operation can be continued beyond 1 year on lower-duty cycles by using the batteries to support the power demand. Degradation in other satellite subsystems and a gradual decrease in spin speed will not affect operation for several years.

The Syncom II satellite system consists of the spacecraft, ground-communications terminals, and telemetry and command ground-control stations. A computing facility for determination of proper orbit correction data is a necessary adjunct to the Syncom II system during critical orbit adjustment periods. The Minitrack network is used in satellite tracking.

The spacecraft was designed to be launched by the Thor-Delta vehicle and incorporates a solid-propellant apogee motor for changing from the elliptical-transfer orbit to a nearly circular synchronous orbit.

Communications ground stations are provided by the U.S. Army Satellite Communications Agency. Equipment for measuring range and range rate was supplied by NASA and was used in conjunction with the ground communication stations. One communication ground station was aboard the U.S.N.S. *Kingsport,* anchored in the port of Lagos, Nigeria. The other principal station is located at Lakehurst, N.J. A station at Fort Dix, N.J., is used as a backup to the Lakehurst station.

The telemetry and command ground-control stations are furnished by Hughes Aircraft Co. The primary station for spacecraft control and receipt of telemetry data during the launch and orbital period was aboard the U.S.N.S. *Kingsport* at Lagos. A station at Johannesburg, South Africa, served as a backup to the Lagos station during the launch and orbit-adjustment period. After orbital adjustment was completed, principal control was assigned to a telemetry and command station located at Lakehurst.

Satellite tracking was done by two methods: Johannesburg Minitrack station tracking of the spacecraft-communications signal, and telemetry and command-station tracking of the spacecraft-telemetry signal. The Minitrack data were used for initial orbit determination. The communications-station tracking data were the most accurate and provided a determination of spacecraft spin-axis orientation. Telemetry and

command station tracking was less precise than the other method, and was used as a backup.

Because of launch vehicle limitations, Syncom was placed in an inclined orbit rather than an equatorial orbit. The Syncom orbit is inclined approximately 32 degrees to the equatorial plane. This in no way, however, affects the validity of the results of the experiments.

To accomplish this, a Thor-Delta three-stage vehicle was used to place the satellite in an elliptical-transfer orbit with an apogee equal to the synchronous altitude of 19,300 nautical miles. When the spacecraft reached apogee, a solid propellant motor, which was an integral part of the spacecraft, was fired to furnish the additional velocity required to circularize the orbit at this altitude. At the completion of this maneuver the spacecraft was in an orbit that was slightly low in energy and was drifting in an easterly direction at a rate of approximately 8 degrees per day. This was well within the tolerances of the system. The spin axis at this time was in the orbital plane. Two changes in the spacecraft position were now required to put it in its intended position at 55° W. longitude with the spin axis normal to the orbital plane: (1) the satellite drift had to be changed from eastward to westward, and (2) the spin axis had to be rotated through 90 degrees.

The first correction consisted of an increase in energy or velocity to change the direction of the drift. The drift rate was changed from 8 degrees/day eastward to 4.6 degrees/day westward. The satellite spin axis was then rotated 90 degrees. This maneuver also changed the drift rate to about 7 degrees/day westward. By August 18, 1963, the satellite was essentially stopped at 55° W. longitude with a drift rate of 0.0012 degree/day. As of April 16, 1964, it was drifting westward at a rate of 1.3 degrees/day and was at approximately 105° W. longitude. This drift rate and position was the result of natural orbit perturbations and exercises performed with the control system.

Figure 9 shows an artist's conception of this launch sequence. The reorientation of the spacecraft is shown being accomplished prior to the velocity correction. The order in which these maneuvers are performed depends on the change required and is chosen to conserve the control capability as much as possible. Figure 10 shows the ground track of the satellite through launch and the first few orbits. The final position over 55° W. longitude is also shown.

Figure 11 is a photograph of the spacecraft. A major part of the spacecraft consists of the velocity- and attitude-control system. There are two independent systems: one using hydrogen peroxide and the other using nitrogen gas. The hydrogen peroxide system is more efficient in terms of spacecraft weight for a given amount of control and, as a result of experience gained with this spacecraft, will be the only type carried on future spacecraft of this kind. The nitrogen system was carried on Syncom because of a lack of experience with a hydrogen peroxide system in this mode of operation.

The communications subsystem contains two transponders: one narrowband, and one wideband. The narrowband transponder is required to relay, with high quality, two voice-modulated carriers (either FM or PM) between ground terminals having the characteristics listed in Table II. The wideband transponders transmit to the ground a reference signal derived from the master oscillator, which is used on the ground in a range and range-rate measurement system. The frequency of this reference signal falls in the passband of the ground receiver low-noise preamplifier.

TABLE II.—*Ground Station Characteristics*

Transmitter power	20 kilowatts
Transmitter antenna	30-foot-diameter parabola, 50 percent efficient, plane-polarized
Transmitter frequency	7360 ± 5 Mc
Transmitter modulation	Angle modulation only (FM or PM)
Transmitted signal, RF bandwidth.	80 kc
Receiver frequency	1815 ± 5 Mc
Receiver antenna	30-foot-diameter parabola, 50 percent efficient, plane-polarized
Receiver preamplifier bandwidth.	10 Mc
Receiver IF bandwidth	100 kc maximum

The communications subsystem employs a frequency translation type of transponder having a 2-watt (nominal saturated power output) traveling-wave tube for its power amplifier. The main beam of the transmitting antenna is broad enough to encompass the Earth at all times.

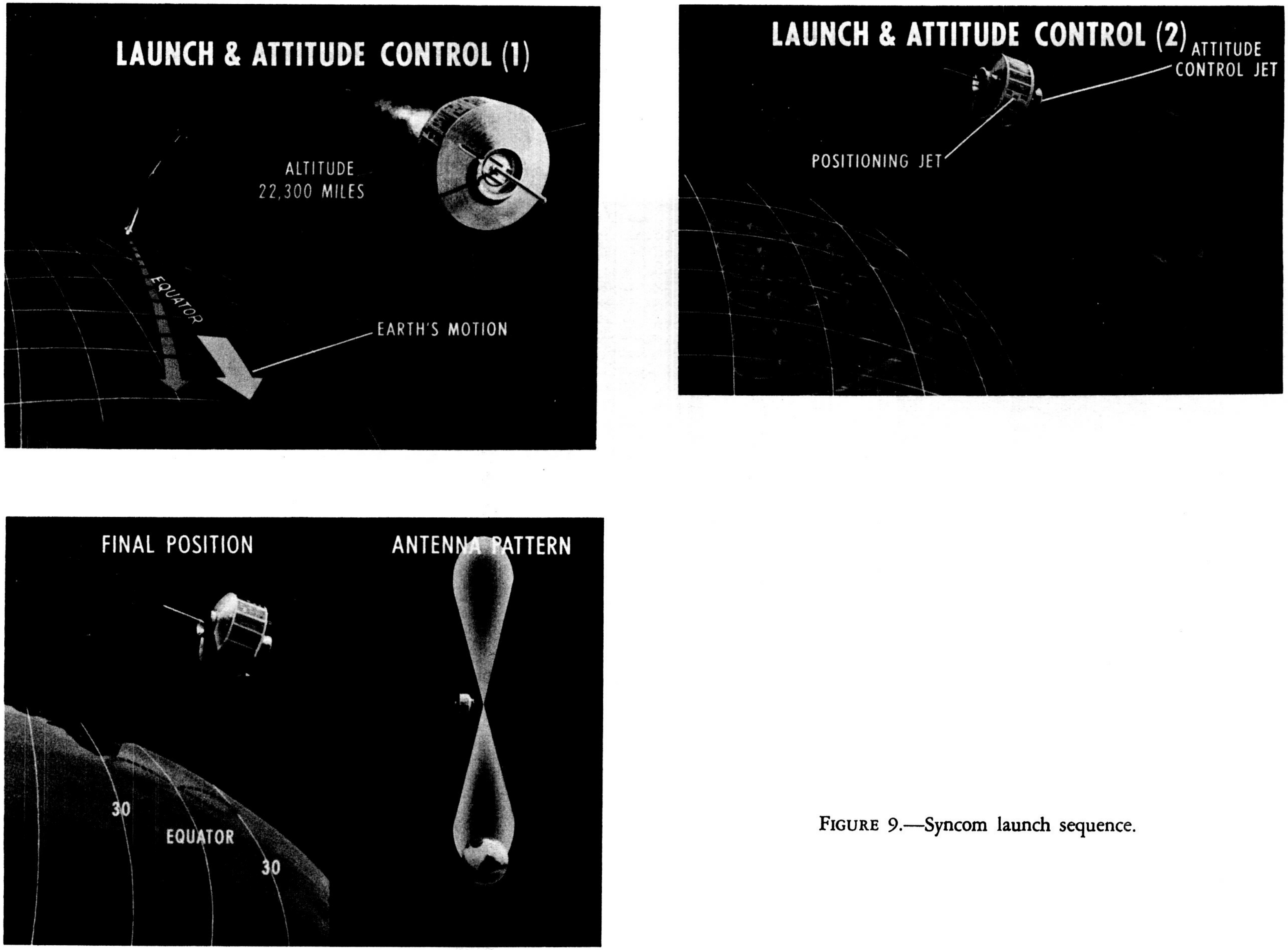

FIGURE 9.—Syncom launch sequence.

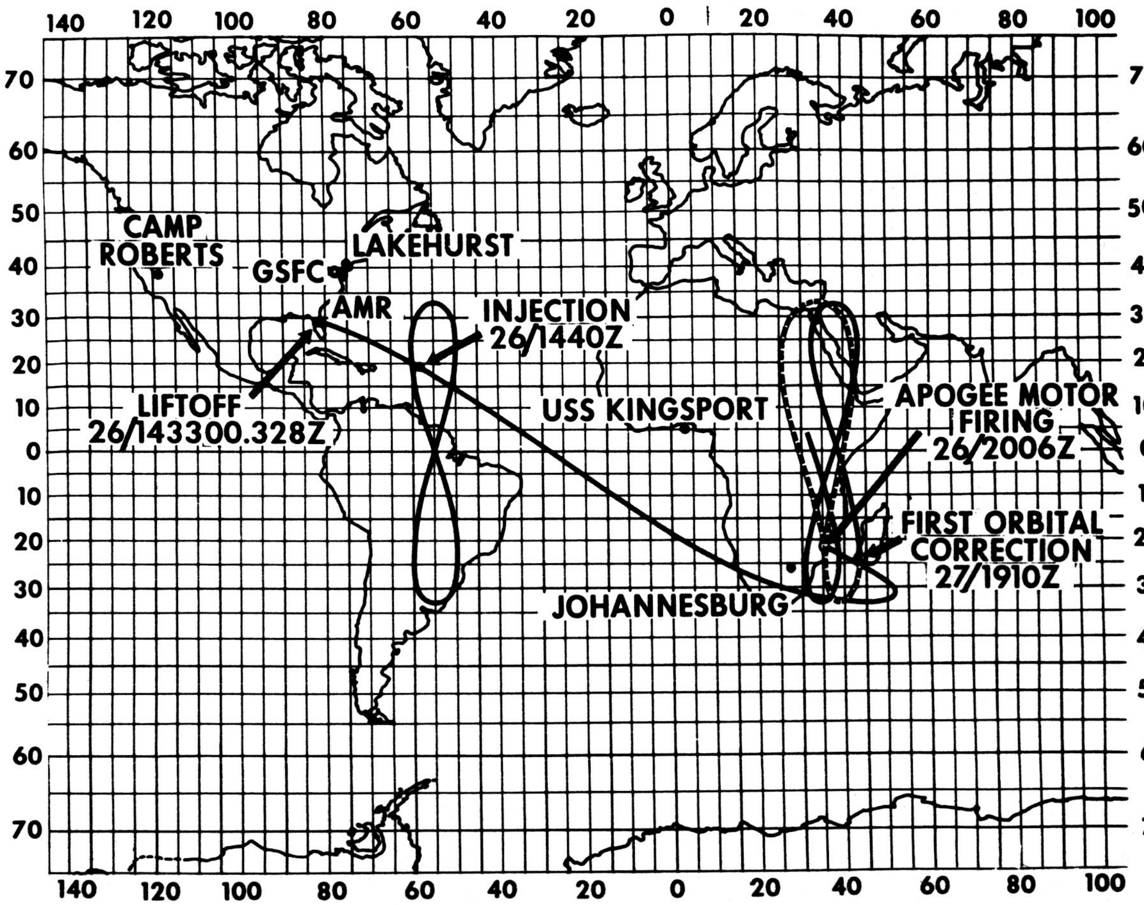

FIGURE 10.—Syncom ground tracking.

The spacecraft power supply and thermal design allows for continuous operation of the communications system except during and shortly after periods of eclipse.

Some of the more important characteristics of the transponder are listed in table III. The transponders are interconnected in a manner that will allow either receiver to drive either transmitter. Only one receiver and one transmitter may be used at a time, the selection being made by ground commands. The interconnections among antennas, receivers, and transmitters are accomplished by stripline hybrid networks and a coaxial switch. These units, along with the receiver input mixers and preamplifiers, are packaged in the central member of the structure. All other units are mounted along the outer cylinder.

The signals received by the slot-dipole antenna are introduced with less than 1 db loss into the mixer of the ON receiver. This is accomplished by using half-wave lengths of cable between the input junction and the mixers and by back-biasing the crystal detectors of the OFF receiver, causing a high impedance to appear at its input junction. The received signals are converted to intermediate frequencies in the mixer with a reference frequency, 7396 Mc, that is the 256th harmonic of the master crystal oscillator which operates at 28.8917 Mc.

The frequency multiplication is accomplished in eight doublers, of which all but the first involve the use of varactor diodes connected push-push in efficient duo-mode networks. The first doubler uses a conventional transistor circuit. When using the narrow-band transponder, the two IF signals are amplified in a common linear amplifier consisting of a preamplifier

having a 3.5 db noise figure and a postamplifier, with a combined gain of 90 db. At this level, representing a combined carrier power of approximately 1 milliwatt, the signals are split into two channels having separate filters, limiters, and squelch circuits which are used to prevent receiver noise from loading the transmitter when a carrier is absent.

TABLE III.—*Transponder Characteristics*

Transmitter type	Traveling-wave tube
Transmitter power output	2 watts (nominal)
Transmitter carrier frequencies.	1814.969 Mc, 1815.794 Mc
Transmitter reference frequency.	1820.177 Mc
Beacon power	100 milliwatts
Receiver type	Frequency translation
Receiver carrier frequencies:	
Narrowband	7361.275 Mc, 7363.000 Mc
Wideband	7362.582 Mc
Receiver noise figure	10 db
Receiver channel bandwidth:	
Narrowband	500 kc (each channel)
Wideband	5 Mc
Antenna type	Skirted collinear slot dipoles
Receiving antenna gain	2 db (excluding losses)
Transmitter antenna gain	6 db (excluding losses)
Total transponder weight	103 ounces (each)
Total transponder power consumption.	14.6 watts

A portion of the master-oscillator power is added to the receiver signals after they have been limited, and the combined signals are passed through a common limiter and introduced into the second mixer. The reference frequency of the second mixer is 1849 Mc, the 64th harmonic of the master oscillator. The output signals are filtered and introduced into the interconnecting hybrid which drives both transmitters, at a power level of 1 milliwatt each.

The wideband transponder is the same as the narrowband except for the IF amplifier. The signal is received from the postamplifier and is further amplified and limited. There is no squelch circuitry associated with the wideband transponder. The beacon signal is added in the same way as the narrowband case.

The transmitters are traveling-wave tubes having a signal gain of 33 db, and nominally 2 watts of power output. The dc power for all tube elements is supplied through dc-to-dc converters, the inputs of which are regulated −24 volts. The power out of the ON transmitter is directed to a collinear slot array antenna by a latching coaxial switch.

The telemetry subsystem consists of two phase-modulated 136-Mc transmitters; two frequency-modulated, time-division multiplexed encoders with analog telemetry inputs; and an antenna unit shared with the command subsystem by frequency diplexing.

A turnstyle antenna oriented at 25 degrees to the spin axis of the spacecraft is used for command and telemetry. Gain is essentially isotropic, the variations with spacecraft attitudes ranging from a maximum of +0.5 db within 11 degrees of the perpendicular to the spin axis to a minimum of −3.2 db at the worst axis orientation.

The antenna is constructed of four quarter-wave whips at 90-degree intervals around the spacecraft circumference. The whips fold parallel to the spacecraft axis during ground handling and launch. Although this arrangement results in antenna detuning and mismatch, signal strengths during prelaunch checkout and liftoff tracking are sufficient because of proximity.

SUMMARY

On August 12, 1960, NASA launched the first satellite, Echo I, designed to investigate the use of artificial satellites in nonmilitary communication systems. This first passive communications satellite has been followed by Telstar I, Relay I, Syncom I, Telstar II, Syncom II, Relay II, and Echo II. All but Echo I and Echo II are active satellites, and all but Syncom I have been highly successful.

Successful communications experiments have been conducted by several agencies using the passive satellites Echo I and Echo II, including experiments by the United Kingdom and the U.S.S.R. with Echo II.

Telstar I, Telstar II, Relay I, and Relay II all have been used in intercontinental experiments and demonstrations. Relay I has had a lifetime of over 16 months in orbit.

Syncom I was successfully launched, but the electronic equipment failed to operate in orbit. Syncom II has been very successful and has been used to demonstrate our ability to place a satellite in a 24-hour orbit and control its position there.

The state of the art has been taken to the point where the Communications Satellite Corp. is now planning an interim system for commercial use and making long-range plans for a more sophisticated system.

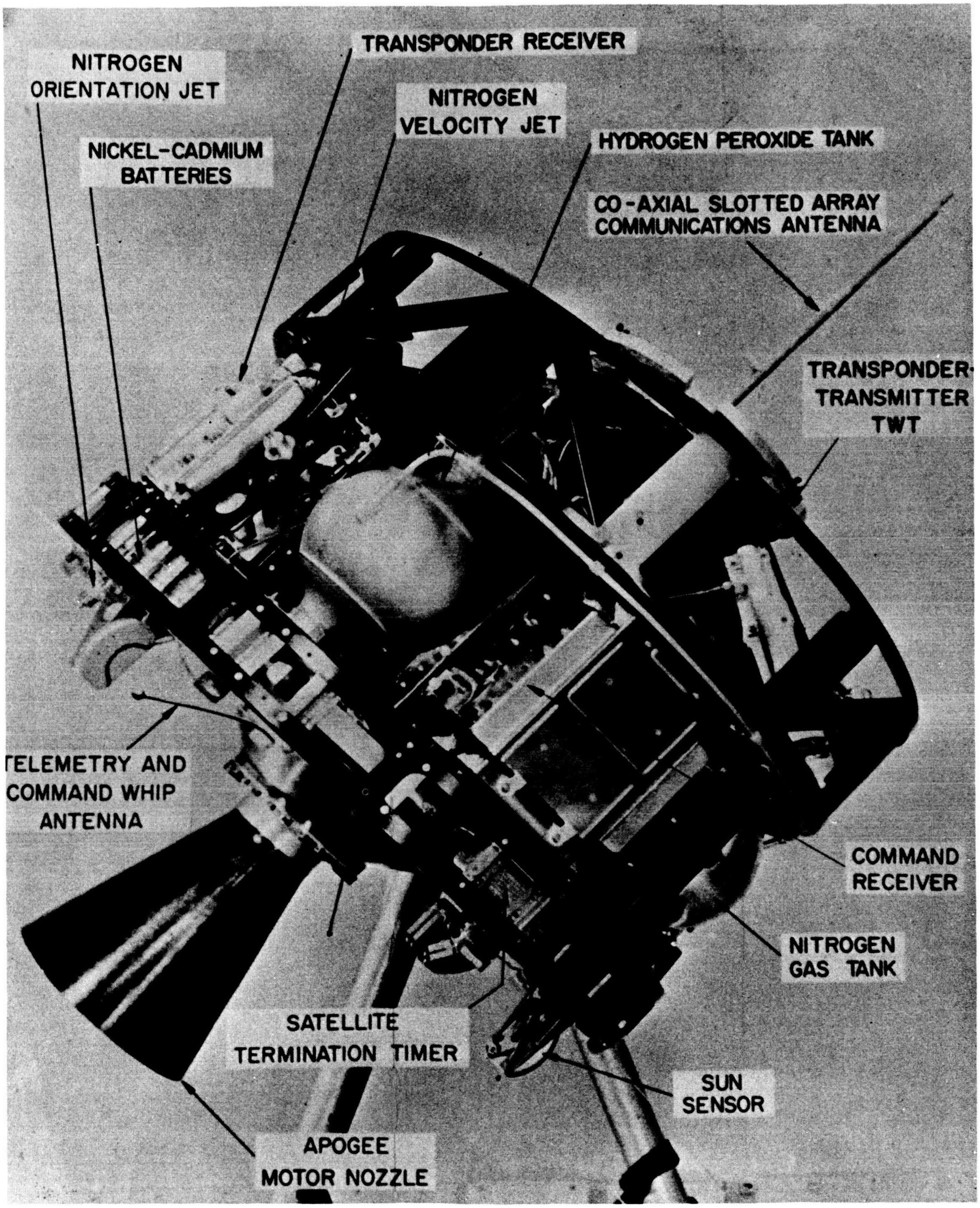

FIGURE 11.—Syncom II.

30343

LIVING IN SPACE

Chairman
ROSS A. MCFARLAND
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N64-30343

INTRODUCTION TO LIVING IN SPACE

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In the preceding sessions of this conference many of the leaders in the space program have discussed the problems of placing men in space, as well as machines in space. Considerable attention is also being devoted to the practical uses of satellites, and related areas. Dr. Werner M. von Braun gave a very inspiring presentation on the future of space. He emphasized the contributions being made to many aspects of modern life, and he clearly portrayed the nature of things to come and the possible impact of the space program in absorbing the energies of men in the future. One might interpret Dr. von Braun's views to imply that space activities eventually may be substituted for the material and psychological needs which in the past have led to war. Thus, the exploration of space eventually may prove to be "The Moral Equivalent of War," as reminiscent of William James' famous essay on this subject. The objective of our program in this session is to discuss some of the accomplishments and problems relating to *Living In Space.*

First of all, it is important to note that the National Aeronautics and Space Act of 1958 requires that ". . . the aeronautical and space activities of the United States shall be conducted so as to contribute materially . . . to peaceful and scientific purposes. . . ." In other words, those responsible for the space effort must also be concerned with the social, economic, and scientific ramifications of the national space program for our society. In this conference on the peaceful uses of outer space, we are sharing in these objectives. Accordingly, it is appropriate to examine some of the implications of the national space program for medicine and related biological sciences.

It may be too early to appraise accurately the impact of the space effort on medicine. It is possible, however, to examine the role of medicine in areas relating to living in space. The basic objective is to develop principles relating to the avoidance of disease and the prevention of injury. The real goal, however, is not simply *marginal* survival. An attempt must be made to predict and maintain *optimum* human performance.

In order to achieve these objectives relating to human performance in space, it is necessary to consider the interaction between the engineering and medical sciences, or, as commonly expressed, the *trade-offs* or compromises required in the design of equipment. Coordinating the efforts of design engineers and biological scientists has resulted in more efficient and safer aircraft to fly within the Earth's atmosphere, and this objective can also be accomplished for vehicles to operate in space.

It should be emphasized that aerospace medicine involves a team approach including the disciplines of psychology, physiology, biology, medicine, and engineering. Often there is a problem of communication and understanding between the physical and biological scientists. In practice, the engineer and physician, finding themselves as joint participants in a project, are forced to find a common mode of expression—obliged to make their ideas and solutions useful to each other. Thus, there develops an integration between medicine and engineering. Understanding has increased with time, and significant contributions have resulted from a joint effort.

The medical sciences of today, as is equally true of the aerospace sciences, would be very limited if the physician's experience did not include knowledge of the manner in which man responds to his *total* environment. Indeed, the sciences of molecular biology and the art of medicine constitutes only a small

fraction of the knowledge required for the care of individual patients and the practice of public health. With the increasing control of communicable diseases, the patient is not as great a threat to the community as the community and its byproducts are a threat to the patient. Likewise, in the exploration of space, it is the hostile environment which must be conquered, whether natural or man made.

One professor of medicine, Dr. John Parks of George Washington University, has made the following points about environmental health, in answer to the question, "What is the nature of that threat in an *effluent* society?"

> It is air pollution and its effects on the cardiopulmonary system; it is water pollution and its relationship to hepatitis; it is the effect of urban noise and auto traffic on the nervous system; it is the body-burden of radiation and its widespread effects; it is the chemicals of the work space; it is the great unknown of pesticides. Surely physicians, who for centuries have fought and conquered the great unknowns of disease, will join in the common attack on these environmental problems.

These statements are directly relevant to space medicine with only slight rephrasing.

We ordinarily think of the relationships between aerospace medicine, preventive medicine, and public health as four general areas.

ENVIRONMENTAL INFLUENCE ON HUMAN HEALTH AND PERFORMANCE

The physician working in the field of bioastronautics is vitally concerned with the effects of the environment on human health and performance. In most cases, physical or chemical hazards are involved. His ultimate task is to establish *scales* which relate duration and intensity of exposure to human tolerance and performance. These must be stated in terms which are useful to design engineers. There is direct applicability of most of these design criteria to preventive medicine here on Earth. Thus, there is a direct interrelationship between the environmental health sciences and space medicine. Radiation, heat and cold, toxic chemicals and barometric pressure are but a few of the areas common to both fields. Obviously, means of protection against these hazards in space flight should contribute significantly to the control of hazardous situations in industry.

There are many other examples of this interchange of knowledge and techniques. Studies of weightlessness on various biological organisms show the effect of gravity on cellular growth and differentiation, and other physiological effects such as decalcification. The use of pressure-suit-type devices may aid in venous return of blood to the heart in certain types of patients. The mechanisms by which microbial spores are transported by air are highly important to both biology and medicine; there are direct implications for reducing the spread of agricultural crop diseases and for protecting persons suffering from allergies. The use of hyperbaric oxygen in certain surgical procedures is proving to be of interest in a variety of clinical conditions.

THE DESCRIPTION AND MEASUREMENT OF "NORMAL HEALTH"

A general principle in industrial medicine is the effective matching of men and jobs. Implicit in this procedure is knowledge of the characteristics of both the man and the job. The selection of astronauts and the design of their training program are based essentially on this procedure. However, criteria for selection were essentially nonexistent at the outset. Because of the need for this data in the selection process, a great deal of information on healthy individuals, with and without the factor of stress, has been developed within studies in aerospace medicine. The immediate usefulness of this type of information to clinical medicine is obvious.

THE ALTERATION OF BASIC BIOLOGICAL MECHANISMS TO INCREASE OR TO PROLONG USEFUL ADAPTATION

The specialist in aerospace medicine is vitally interested in basic physiological mechanisms. His interest is directed not only toward an understanding of these bodily systems, but equally toward prediction of behavior in times of anticipated stresses. Knowledge of the mechanical characteristics of the vestibular apparatus allows the aerospace physician to predict the distortion of visual perception and disorientation which would occur to a tumbling or spinning astronaut. The otolaryngologist uses this same knowledge when he traces through a causative disease process. Closed ecological systems, withdrawing of normal sensory inputs, variations in oxygen pressure, and the prolonged effects of certain gases and toxic agents provide a few illustrations of other areas under current study.

Means of altering the biological organism to increase resistance to disease are of common interest to

clinical and aerospace medicine. For example, findings in the field of antiradiation drugs obtained from research in one specialty are useful to the other.

THE REFINEMENT OF INSTRUMENTS FOR OBSERVING, RECORDING, AND ANALYZING DATA

The man-in-space program requires that a large volume of information about the astronaut be remotely collected and transmitted instantaneously to ground-based observers. A large number of tools have been perfected during the past few years to observe, record, and analyze physiological data. These developments are often referred to as an important contribution of bioastronautics to clinical medicine. A wide variety of sensors have been developed, as well as miniaturized telemetry devices and computers. Many of these have found immediate application in surgery, medicine, and anesthesiology. The transmission of physiological data via the communications satellite Relay I between England and a major medical center in the United States in order to make a diagnosis for an individual patient provides a dramatic illustration.

STIMULUS OF SPACE RESEARCH

After this brief summary of the relationships between space and terrestrial medicine, one may ask the question whether these contributions could have arisen without the stimulus and challenge of the space program. Analysis has suggested that while a few developments might have appeared, most would not. A Brookings Institute Report, "Implication of Peaceful Space Activities for Human Affairs," written in 1960, noted that: ". . . major breakthroughs in science and technology have always produced acceleration in the rate of succeeding innovation, but space activities appear to be pushing the pace of innovation to unprecedented levels."

The Mercury program found man not only an effective link in a complex system, but on three of seven missions, an indispensable element in terms of their success. Many have asked, "Why send a man on such a dangerous mission? Wouldn't it be better to use instruments?" One space scientist has recently pointed out that as we approach these more advanced studies we need a skilled interpretation of the broad situation from which alternative courses of action can be weighed objectively. If we were to try to design an instrument to exercise this broad comprehension, it would look surprisingly like a man.

More specifically, a human operator in the spacecraft can: (1) report upon and cope with unexpected events and phenomena; (2) make generalizations from specific observations; (3) profit from experience as the mission progresses by assimilating bits of pertinent information into intelligible form, and reprogram as necessary; (4) improvise and use flexible procedures which contribute to the success of a mission; and, finally, (5) exercise judgment. Because of these abilities it can be seen that a well-trained astronaut is very essential when there is a need for flexibility and when there is an extreme range of alternative conditions.

The experience obtained from the Mercury project has provided a basis for judgment in planning later man-in-space programs. The results demonstrate that man can survive for short intervals in space. The effects of missions of longer duration are unknown. Prominent among these are the effects of weightlessness and the interaction of this variable with other hazards. Man's function and behavior while breathing an artificial atmosphere, altered as to pressure and composition for long periods of time, are as yet unknown.

N64-30344

THE MEDICAL SUPPORT OF MANNED SPACE FLIGHT

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After the many distinguished speakers who have been on this program, there is no need to justify spaceflight or to try to provide lists of good engineering spinoffs. In a recent talk, Dr. Teller stated that the greatest benefit from the space program was achieved with the investment of the smallest amount of weight which is as it must be in this program. This benefit was the acquisition of knowledge. At this time no one can say exactly how great this knowledge will be or exactly what tremendous applied benefits may result. There can be little doubt, however, that benefits will accrue to many areas of our life. There are some medical payoffs or spinoffs to this program.

Placing man in a hostile environment has caused us to require that he be monitored to determine the response of his physiology to this environment. We are in effect stretching our stethoscope 100 miles from the Earth's surface instead of using it at the bedside as we did previously. This has required development of bioinstrumentation and telemetering techniques, and these are rapidly reaching into all the areas of the practice of medicine. The impetus of the space program has called for miniaturizing and, if you will, *comfortableizing* such instrumentation in order that we may gain the maximum physiological data on man over long periods of time under very trying situations. Figure 1 shows the array of such instruments used for the Cooper flight. New instruments and methods are constantly being developed, some of which will be of value to us, but many of which will be of value to the practice of medicine on Earth.

Another very interesting outcome of this entire program has been the study of normals. As flight surgeons, we find ourselves concerned principally with the study or care of the normal individual placed in an abnormal environment, whereas the Earthbound physician studies the response of an abnormal individual to a normal environment. In obtaining our many hours of baseline data and then following these normal individuals into a stressful environment, we have found many interesting pulse rates, respiratory rates, and electrocardiographic findings which we be-

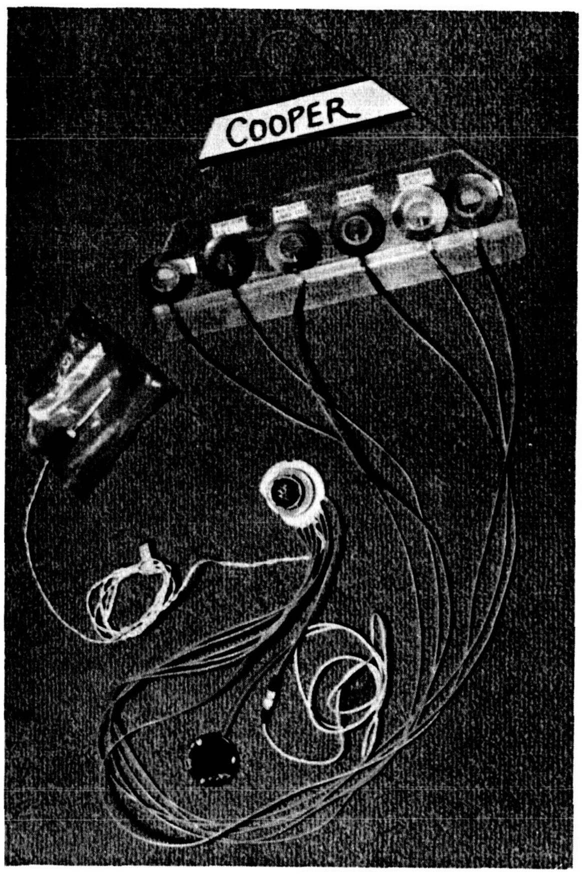

FIGURE 1.—Bioninstrumentation for Cooper flight.

lieve are entirely normal in these situations. As normal man is monitored for prolonged periods, further information will be obtained which will be of value in the study of disease and in establishing new normals. We might look a short distance further and see the uses which bioinstrumentation will be put to in the development of central monitoring stations in hospitals and recovery rooms. This should help in alleviating some of the personnel shortages in hospitals and provide the patient with better all around care at critical times. There are many other areas which I am sure you could think of, but this evening I would like to discuss with you some of the results which we obtained on Project Mercury and then briefly relate these to our future spaceflight programs.

In spite of the vast numbers of people and network assembled to carry out manned spaceflight projects and directed from positions at the Mercury Control Center, now to be the Mission Control Center, we have not come very far from the problems involved in the care of the pilot flying the old World War I Jenny in providing the care for the pilot placed in this precarious position atop the Mercury or Gemini launch vehicle, tied down in a confined space but able to see unbelieveable views of our Earth from his orbiting position. We are still plagued by the basic problems of eating, sleeping, bathing, shaving, handling body waste, and just general habitability.

The nature of the challenge posed by the development of a medical support program called for ground rules applicable to these aspects, and not unlike those outlined for the overall project by Dr. Williams:

1. Man is being thrust into a truly unknown environment and his reactions to this environment are relatively unknown.
2. The simplest and most reliable approach should be used.
3. Off-the-shelf items and existing technology should be used wherever possible.
4. Attempts would be made to provide the best protection and monitoring capable within the operational constraints of the mission.

Many lessons have been learned from this first experience of the free world with manned space-flight operations. The responsible medical community had very honestly attempted to evaluate potential problems based upon knowledge at that time. In doing this, several possible ogres were raised which, it appears, this program has killed or at least wounded. Weightlessness is a good example of the many barriers to man's entry into space which were raised prior to this program. Some of the dire physiological effects predicted as a result from exposure to this condition and, therefore, thought to be limiting to space flight were anorexia, nausea, sleepiness, sleeplessness, fatigue, restlessness, euphoria, hallucinations, disorientation, decreased G tolerance, urinary retention, diuresis, muscular incoordination, muscle atrophy, gastrointestinal disturbance, and demineralization of bones. As a result of our flights to date, few of these remain of concern, although our total experience in the free world is limited to 34 hours.

Another area in which there were dire predictions is in the psychological response to the isolation of space. Our astronauts have certainly not been isolated in space but have generally commented on too much Earth contact. There has been no evidence of any breakoff phenomenon or any aberrant psychological reaction of any sort. Thus, while we had no serious problems in space, the present conclusions can only be based upon the duration of flights thus far flown—34 hours. Each mission has been used as a means of evaluating the next step into space, and it is believed that the six manned missions in this program have laid the groundwork for future programs.

CREW SELECTION AND TRAINING

The medical portion of the selection program had as its objectives the provision of crewmembers who (1) would be free of intrinsic medical defects at the time of selection, (2) would have a reasonable assurance of freedom from such defects for the predicted duration of the flight program, (3) would be capable of accepting the predictable psychophysiologic stress of the missions, and (4) would be able to perform those tasks critical to the safety of the mission and the crew. The selection board found themselves viewing already trained test pilots somewhat in the same manner as cadets entering a training program are viewed. Small numbers were selected, leaving little excess for attrition. In view of these objectives, the group was culled by records review, interview, and testing until a final group was given a rigorous medical examination at the Lovelace Clinic in Albuquerque, N. M. This examination was followed by a stress-testing program at Wright-Patterson Air Force Base, Ohio (fig. 2). The results of these examinations were reviewed by the participating physicians, and the candidates were given a medical rank order. This

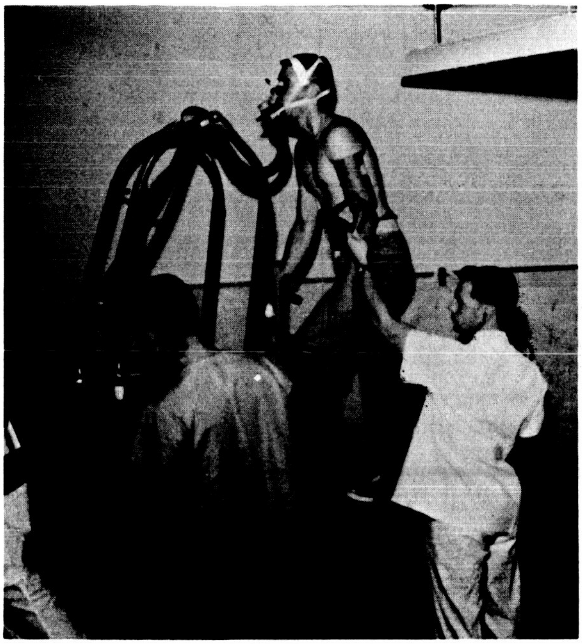

FIGURE 2.—Stress testing on treadmill.

rank order was then presented to a board which selected the original seven astronauts.

In retrospect, it can be said that the results of this program were adequate in view of the fact that the assigned astronauts have successfully completed their flight missions. This early program has been of assistance in the development of current selection programs with the USAF School of Aerospace Medicine. The stress testing in the initial selection efforts has been deleted since it was found to be of little value in a group who had already been very thoroughly stress tested by virtue of their test-pilot background. Stress testing has become a part of the training program with a selection in depth carried on during the training.

The training program has included a series of lectures on the anatomy and function of the human body, and the series has proven to be of great value during inflight monitoring and discussion of potential medical problems. Every attempt has been made to use engineering analogies where possible and to impress the flight crews with the fact that the human organism and its many systems must be monitored as thoroughly as the engineering systems if mission success is to be assured.

There has been no formal physical-training program, but each astronaut has been charged with maintaining his fitness through programed exercise of his choice. A wide variety has been used by the group. Medical advice was offered and the importance of regular training periods was stressed during the preflight preparation period. A plateau should be reached, and, although no specific level is specified, it is believed the astronaut is better prepared to withstand the flight stresses if he maintains a state of physical fitness.

MEDICAL MAINTENANCE AND PREFLIGHT PREPARATION

The medical maintenance during this program consisted of the routine medical care, similar to that provided specialized groups of aircraft pilots, annual physical examinations and special physical examinations performed before procedures such as altitude-chamber runs, pressure-suit indoctrinations, and centrifuge runs. The flight schedule with its necessary preflight spacecraft checkout procedures, simulated flights, and launches, frequently exposed each flight crewmember to severe physical examinations within a given year. An attempt was made to make these physical examinations serve several purposes such as qualifying the individual for his annual physical, being ready to participate in a given procedure, and collecting baseline data. Having flight surgeons monitor astronauts participating in all stress exposures and training exercises proved to be extremely valuable preparation for the flight mission. Preflight physical examinations added to the necessary medical status evaluations; and, throughout these activities, a close and frequent contact was maintained between flight crews and flight surgeons. This close association also provided excellent preventive medicine practice among the flight crews.

The preflight physical examinations were to serve two basic purposes. First, they should allow the flight surgeon to state that the astronaut was qualified and ready for flight. Second, they should provide a baseline for any possible changes resulting from exposure to the space-flight environment. The flight surgeon appears best qualified to determine whether the astronaut is medically ready for flight. Early in the program, the search for unexpected changes in body systems as a result of exposure to space flight dictated specialty examinations of various body systems. A team, assembled from the Department of Defense, included specialists in internal medicine, ophthalmology, neurology, psychiatry, and laboratory medicine.

The same specialties have continued to be represented, but certain items of the examinations have been modified as knowledge of the lack of serious effects of flight on the astronaut was gained. Prior to the selection of a flight astronaut for a given mission, the medical records of those being considered are reviewed in detail and a medical recommendation given to the operations director. In addition to the annual and pretraining examination, it was determined that a thorough evaluation of the flight astronaut would be made 10 days prior to the scheduled mission to assure management and the flight director that the astronaut was indeed ready for the mission. This examination included a medical evaluation of both the flight astronaut and his backup. Two days prior to the mission, the detailed physical examination was completed by the various medical specialists and the necessary laboratory work was accomplished. On flight morning, following a brief medical examination, a final determination was made as to the readiness of the astronaut for flight. This examination was principally concerned with noting any recent contraindications to flight which may have developed. While early in the program other specialists participated in this examination, on the last two missions, the participation was reduced to that by the flight-crew surgeon.

The postflight medical examinations were initially made by the Department of Defense recovery physicians stationed aboard the recovery vessel. On the early missions, the astronaut was then flown to Grand Turk Island and was joined there by the team of medical specialists who had made the preflight examination and by the flight-crew surgeon. As the flights became longer and recovery was accomplished in the Pacific Ocean, the plan was changed and one of the NASA flight surgeons was predeployed aboard the recovery carrier to do the initial postflight examination and debriefing. On the MA–8 mission, Walter Schirra's flight, the Director of Medical Operations and the medical evaluation team deployed to the Pacific recovery site several hours after recovery, and this was not only a tiring experience, but necessitated that a great deal of the examination and debriefing be done prior to their arrival. The MA–9 detailed postflight specialty examination was then conducted at Cape Canaveral when the astronaut returned from the recovery site. In our experience, the retention of the specialty examination team at a mainland launching or debriefing site is the preferable plan of action.

Early in the preflight preparations, it was determined that there was a need for many practice runs of various procedures. These runs were accomplished by doing the actual flight-type preparation for each of various preflight procedures. A medical countdown (table I) was developed with specific timing of the various events and coordination with the blockhouse and range countdown. In order to have no delay

TABLE I.—*Aeromedical Countdown*

Activity	Countdown time		Planned time			Actual time		
	Pad (T)	Aeromedical (A)	A.M. E.S.T.	Minutes		A.M. E.S.T.	Minutes	
				Duration	Total		Duration	Total
Awaken	T–220	A–170	2:50	35	35	2:51	31	31
Breakfast	T–185	A–135	3:25	30	65	3:32	33	64
Medical examination	T–155	A–105	3:55	15	80	3:55	16	80
Partial dressing	T–140	A–90	4:10	5	85	4:11	4	84
Sensor placement		A–85	4:15	10	95	4:15	9	93
Suiting		A–75	4:25	20	115	4:24	18	111
Suit/sensor checkout		A–55	4:45	15	130	4:42	12	123
Hangar S to transfer van		A–40	5:00	10	140	4:54	6	129
Transfer van to launch pad		A–30	5:10	20	160	5:00	*27	156
Ascend gantry		A–10	5:30	10	170	5:27	6	162
Insertion	T–140	A–0	5:40	140		5:33	151	
Launch	T–0		8:00		310	8:04		313

*9 minutes spent at the bottom of gantry for weather briefing, mission briefing, etc., by backup astronaut.

in the scheduled launch, a great deal of practice in this countdown was necessary. It has continued to pay dividends in the later missions.

Prior to the first Mercury launch, consideration was given to the necessity for isolating the flight crew in order to prevent the development of some communicable disease immediately prior to or during flight. It soon became evident, however, that such isolation was impractical in view of the numerous requirements upon the flight crew during the 2 weeks prior to launch. Many activities required the presence and participation of the astronaut, and the isolation was reduced to attempts to curtail the number of contacts with strangers. As the missions get longer and longer, the situation may have to be reevaluated since the mission could last longer than the incubation period of some diseases. No difficulty was encountered during the Mercury program with the use of only a very modified isolation plan.

One of the basic concepts developed stated that there would be no drugs used as routine measures, but that drugs would be made available for emergency use. Injectors were made available which could deliver their contents through the pressure suit into the astronaut's thigh. During the first four missions, the drugs available in the injectors included an anodyne (a drug for pain), an anti-motion-sickness drug, a stimulant, and a vasoconstrictor for treatment of shock. In the later missions, the injectable drugs were reduced to the anti-motion-sickness drug, a stimulant, and a vasoconstrictor for treatment of shock. For the MA–9 flight medication was reduced to the anti-motion-sickness drug and an anodyne, available both on the suit and in the survival kit (fig. 3). Anti-motion sickness and antihistamine tablets were also made available.

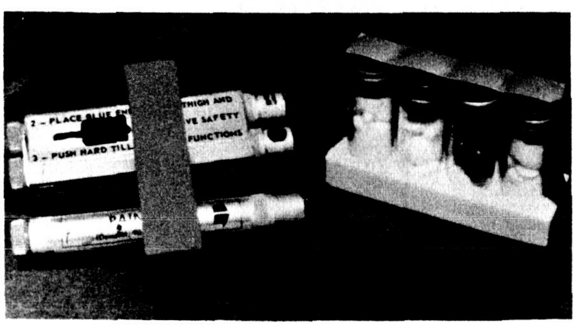

FIGURE 3.—Injectors and pill case used for MA–9 flight.

The astronauts' mental and physical integrity were never in doubt during the mission. As the time for retrofire approached on Major Cooper's mission, a review of the mission tasks made it evident that the astronaut had undergone a long and rigourous work schedule from which he might be expected to experience considerable fatigue, even assuming ideal environmental conditions and full benefit from restful sleep. As has been reported, medication was used for the first time during flight when the dextro-amphetamine sulfate was taken prior to the initiation of retrosequence. Such drugs should be available and plans must be made for their availability both during flight and postflight in the survival kit. The astronaut must always be pretested for effect of the drugs which may be used.

Experience has shown that care must be taken to prevent astronaut fatigue during the final preflight preparations as well as postflight. As launch day grows closer, the demands on the astronaut's time increase. Careful scheduling of rest, activities, and exercise periods are needed. Experience has shown that 48 to 72 hours is a minimum time for postflight debriefing, rest and relaxation following a 34-hour mission. Seventy-two hours should be a minimum for future missions. As missions get longer, this time should be increased.

Early missions required only simple provisions for the collection of urine and blood samples. As the mission duration increased, this became an unworkable procedure; and further, there was a desire to obtain separate urine samples for analysis. The last mission utilized a system for collecting five separate and complete urine samples for later evaluation. This system worked properly but will require modification for future missions. No blood samples have been obtained during flight. Every attempt has been made to combine the various preflight blood requirements in order to require as few vena punctures as possible, both preflight and postflight.

Dietary control has been utilized for approximately 1 week prior to each mission. The first several days were used to assure a normal balanced diet during the rather hectic preflight preparations. In order to prevent defecation during the mission, the low-residue diet was programed for 3 days prior to launch; and the time extended if the launch was delayed. This diet performed its task very satisfactorily during the entire Mercury program; still, indications are that any more prolonged period without provision for defecation

would seem unwise. The in-flight food consisted of tablets, bite-sized and semiliquid tube food on the early missions. On the last mission, the freeze-dehydrated food was added. Problems with crumbling have been encountered with the bite-size food, and difficulty in getting and keeping water in the containers of the freeze-dehydrated food was encountered on the last mission. The assurance of palatable food is necessary, and proper containers and practice in their use appear indicated. It also appears necessary to schedule food and water intake on the flight plan.

MEDICAL MONITORING

The Mercury program provided the free world with the first opportunity for full-time monitoring of man in the space-flight environment. At the start of this program, the continuous monitoring of physiological data from a pilot conducting a mission was a very recent concept. At the time, there were no off-the-shelf items available to allow continuous and reliable physiological monitoring. It was decided to attempt to monitor body temperature, chest movement, and heart action. Standards required that the sensors and equipment be comfortable, reliable, and compatible with other spacecraft systems, and would not interfere with the pilot's primary mission.

It should be realized that the biomedical sensors are used as a means of flight-safety monitoring. The primary purpose is to assist the monitoring flight surgeon in determining whether the astronaut is capable of continuing the mission from a physiological point of view. This information is used as a basis for making go/no-go decisions in the control center. No attempt has been made under the current operational conditions to perform detailed system evaluation or analysis.

A great deal of experience in medical flight control of an orbiting astronaut was obtained through the use of the many range simulations and the several actual flights. The participation in simulations and in flights prior to those which were manned proved to be extremely valuable training exercises for the actual missions. The development of mission rules to aid in flight control was necessary in the medical area just as in the many engineering areas. Gradually, these rules were made less specific so that the evaluation and judgment of the medical flight controller were the prime determinants in making a decision. The condition of the astronaut as determined by voice and interrogation, rather than physical parameters, alone became a key factor in the aeromedical advice to continue or terminate the mission. This is as it should be and follows the lessons which were learned in general medicine wherein numerical laboratory values are not necessarily the final answer. Trend information as shown by at least three stations was shown more reliable than single values.

In developing the flight-control philosophy prior to the first manned flight, it was thought that it would be necessary for the flight surgeon to talk directly to the astronaut very frequently in order to evaluate his physiological state. As operational experience was gained, it became obvious that this was not the case. Information inquiries were passed easily and smoothly through the Cap Com (capsule communication) with the privilege of talking directly remaining should the need arise. It was also thought early in the program that the occurrence of most any medical emergency in flight would require an early or even a contingency landing. Again, as operational experience was gained with the range and with the planned recovery operation, it was determined that the best philosophy was one which held that the astronaut was in a very fast, air-conditioned ambulance on 100 percent oxygen and in most instances it would be better to return him in the spacecraft to a planned recovery area rather than to abort the flight in a contingency area where it might take hours or days to recover him. The physiological parameters monitored are shown in figure 4. Electrocardiographic electrodes were low impedance to match the spacecraft amplifier. They were required to record during body movements and to stay effective during flight durations of over 30 hours. These electrodes functioned well and gave very good information on cardiac rate and rhythm. The value

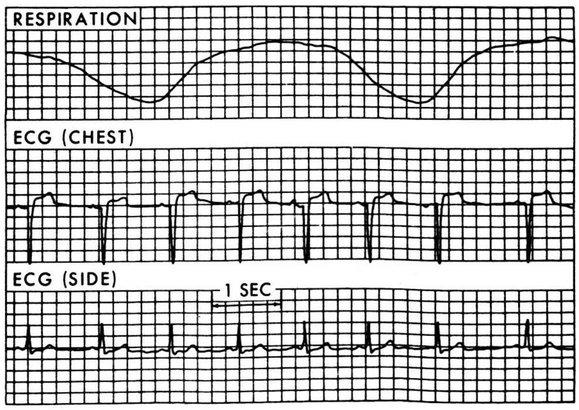

FIGURE 4.—MA–9 biotelemetry sample.

of having two leads of electrocardiograph, even though they differed from the standard clinical leads, was repeatedly shown.

Respiration was at first measured by an indirect method by using a linear potentiometer and carbon-impregnated rubber. This method was changed early in the program to a thermistor kept at 200° F and placed on the microphone pedestal in the helmet. Neither of these methods gave reliable respiration traces during flight, and a change was made to the impedance pneumograph for the last two missions. This device gave very accurate respiration information during most of the flight.

Body temperature was monitored in all missions. Rectal temperature was found to be the most reliable measurement and was used through MA–8. The long duration of the last flight and a desire for more comfort resulted in this thermistor being modified for oral use.

In 1958, the obtaining of blood pressures in flight was considered and then delayed as no satisfactory system was available. Definitive work began about the time of the Mercury-Redstone 3 (MR–3) flight, and the automatic system which used the unidirectional microphone and cuff was developed for use in the orbital flights. This system without the automatic feature was used on the MA–6 mission of Astronaut Cooper. During the MA–7 mission, all of the in-flight blood pressures obtained were elevated, and an extensive postflight evaluation program was undertaken. It was determined that the cause of these elevations was most likely instrumentation error resulting from the necessity for very careful gain settings matched to the individual astronaut along with the cuff and microphone. A great deal of preflight calibration and matchings of these settings was done prior to the MA–8 flight; and on both the MA–8 and the last mission, MA–9, very excellent blood-pressure tracings were obtained.

Voice transmissions have been a very valuable source of monitoring information. The normal flight reports and answers to queries have been used for evaluation of the pilot. In order to insure that the monitors were familiar with the astronaut's voice, tapes of mission simulations with the flight astronaut as a pilot were dispatched to all of the range stations for use in preflight simulations. Inflight photography and, on the last mission, television views of the astronaut had been planned as additional data sources. In Mercury experience, both of these sources have proved to be of very little value in the medical monitoring of the astronaut because of poor positioning of cameras and varying lighting conditions resulting from the operational situation.

The value of the comparison of multiple physiological parameters and their correlation with environmental data has been repeatedly proven. It has been interesting to note that a satisfactory amount of information on current astronaut status can be obtained with the use of such basic vital signs or viability measures.

PHYSIOLOGICAL RESPONSES TO SPACE FLIGHT

One of the basic objectives of the Mercury flights was the evaluation of man's physiological responses to exposure to this space-flight environment. These responses also had implications as to his performance capability in this environment. The stresses of this environment to which physiological responses are elicited include the wearing of the full-pressure suit although not pressurized in flight, confinement and restraint in the Mercury spacecraft with the legs at a 90° elevated position, the 100 percent oxygen 5-psi atmosphere, the changing cabin pressure through powered flight and reentry, variation in cabin and suit temperature, the acceleration force (G force) of launch and reentry, varying periods of weightless flight, vibration, dehydration, the performance required by the flight plan, the need for sleep and for alertness, changes in illumination inside the spacecraft, and diminished food intake.

Sources of data used in evaluating these responses have included the control baseline data previously referred to, data from the biomedical sensors received at both the Mercury Control Center and the range stations, voice responses at these stations and the detailed onboard tape, the onboard film record and television, answers to debriefing questions, and the detailed postflight examination.

In considering these physiological responses, it was found necessary to have a detailed in-flight event history since the peak physiological responses are closely related to critical inflight events. This meaningful relationship is very well demonstrated in considering the pulse responses to the Mercury flights (table II). The peak pulse rates during the launch phase have usually occurred at sustainer engine cutoff. This peak value has ranged from 96 to 162 beats per minute. The peak rates obtained on reentry have ranged from

104 to 184 beats per minute. This peak usually occurred immediately after obtaining peak reentry acceleration, or on drogue parachute deployment. Pulse rates obtained during weightless flight have varied from 50 to 60 beats per minute during the sleep periods to 80 to 160 beats per minute during the normal wakeful periods. Elevated rates during weightless flight can usually be related to flight plan activity, and it is not possible to compare pilots by these data.

TABLE II.—*Pulse Rates*

Mission	Peak at SECO*	Range during weightlessness	Peak during reentry
MR-3	138	108–125	132
MR-4	162	150–160	171
MA-6	114	88–114	134
MA-7	96	60–94	104
MA-8	112	56–121	104
MA-9	144	50–60 asleep 80–100 awake	184

*Sustainer engine cutoff.

Further evidence of normal pulse lability is shown by the response to transferring urine early in the flight and to the observation of the 0.5-g light being on late in the mission. Changes noted in the electrocardiograms have included alterations in the pacemaker activity with wandering pacemakers and aberrant rhythms. All of these *abnormalities* are considered normal physiological responses when related to the dynamic situation in which they were encountered. In-flight blood-pressure values and body-temperature readings have all been within the physiologically normal range.

The six astronauts who have flown have shown themselves capable of normal physiological function and performance during the acceleration of launch and reentry. The vibration produced by launch or reentry has been well tolerated in all cases. There has been no conclusive evidence of disorientation during flight.

The heat loads imposed by the environmental control system have on occasion caused discomfort but have not been limiting factors in the missions to date. The heat loads and decreased water intake have resulted in postflight dehydration. It has been learned that thermal control in the environmental system is of critical importance.

The results obtained from radiation dosimetry on the last two flights revealed that the astronauts have received no more radiation dose than they would have received had they been here on Earth and certainly less than that received during a chest X-ray.

The Mercury program has provided incremental exposures to weightless flight in order to obtain information on which to base predictions of reactions to more prolonged exposures. The crews have uniformly reported that weightlessness is extremely pleasant and restful. In fact, most of the crews think that it is the only time they have been comfortable in a pressure suit. They have conducted complex visual motor coordination tasks proficiently in the weightless environment.

No evidence of body-system disfunction has been noted during the period of weightless flight through any of the means of monitoring at our disposal. Food has been eaten normally. Urination has occurred quite normally in timing and amount, and there is no evidence of difficulty in intestinal absorption in the weightless state. Our one experience with sleep periods (during the Cooper flight) has raised the question as to whether brief periods of sleep in the weightless condition are more restful than the same periods in a 1-G atmosphere. The MA-9 astronaut feels that they are. This question will require further investigation on other flights. In the missions to date, there has been no evidence of the mobilization of calcium.

On the last two missions some postflight orthostatic hypotension, or changes in blood pressure and pulse rate with change in body position, has been noted. This postflight condition has been investigated by the use of the tilt table during the last mission and these results confirm what was only a suspicion on the previous mission. Symptoms of faintness occurred following egress from the spacecraft on MA-9 (Cooper), and on both MA-8 (Schirra) and MA-9 the changes in blood pressure and pulse rate were present for some 7 to 19 hours after landing. In both instances, these changes have been present up until the astronaut retired for the night, a time period of approximately 7 hours; and they have always disappeared by the time of the first check after the astronaut was awakened.

Thus, the orthostatic changes have lasted no longer following the more prolonged flight in the MA–9 position than for the shorter flight; and, in both instances, blood pressure and pulse rate have returned to normal while the astronaut was at bed rest. These findings do cause concern about prolonged exposure without some interim steps for further evaluation of this condition. The Gemini flights will take these findings into consideration.

RECOVERY

The medical support of the overall Project Mercury recovery operation had to meet two basic requirements:

1. The capability of providing prompt, optimum medical care for the astronaut, if necessary, upon his retrieval from the spacecraft
2. The provision for early medical evaluation to be made of the astronaut's postflight condition.

It was considered essential to establish a medical capability for any circumstance under which recovery could occur. The general concept was to provide the best care in the fastest manner possible. The extent of medical care which could be effectively administered to the astronaut during the recovery operation is governed to a large degree by the physical circumstances under which recovery occurs. Consequently, the level of medical support necessary at the different recovery areas varies according to the potential extent to which competent medical treatment can be administered in that area, and the most extensive medical support is properly concentrated in those areas where descent to Earth by the astronaut is most probable.

Since the recovery forces are routine operational units diverted to this operation by the Department of Defense, it also became obvious that the medical support must be obtained through the cooperation of the Department of Defense. Civilian physicians are not available for deployment for the necessary time periods. It will be noted that one of the basic philosophy changes during the program involved a change in emphasis from taking medical care to the astronaut in the early mission to provisions for returning the astronaut to definitive medical care in the later missions.

In the launch-site area, this support included a medical team consisting of representatives of many of the medical specialties. In the early missions, these individuals were deployed to Cape Canaveral (now Cape Kennedy) and were available should the need arise for their use either at Cape Canaveral or, in the event of a requirement for their services in the recovery area, they could be dispatched by aircraft. On the last two missions, it became necessary to develop a team at Tripler Army Hospital, Hawaii, to cover the Pacific area. It became obvious that there were large numbers of highly trained physicians who were merely waiting out the mission in a deployed state with an unlikely probability that they would be utilized.

Careful evaluation of the experience and of sound medical principles involving emergency medical care led to the conclusion that the specialty team could be maintained on standby at a stateside hospital and easily flown either to Cape Canaveral or a recovery site if their services were needed. Other launch-site support was provided by a point team consisting of a flight surgeon and scuba-equipped pararescue personnel airborne in a helicopter. Medical technicians capable of rendering first-aid care were also available in LARC vehicles and in a small boat stationed on the Banana River. A surgeon and an anesthesiologist with their supporting personnel were stationed in a blockhouse at Cape Canaveral to serve as the first echelon of resuscitative medical care in the event of an emergency. Physicians were stationed throughout the recovery areas aboard destroyers and aboard one aircraft carrier in the Atlantic and one in the Pacific. In the early missions each vessel was assigned a surgeon, anesthesiologist, and a medical technician team with the supporting medical equipment chest necessary for evaluation and medical or surgical care.

As confidence was gained in the operations, this distribution was modified to assigning only a single physician, either surgeon or anesthesiologist, to the destroyer. Attempts were made to place a surgeon on one and an anesthesiologist on another vessel nearby. This would allow their teaming up if necessary. The general concept was, however, that they would provide resuscitative care only and then evacuate the astronaut to the carrier in their particular area, where there was a full surgical team. Hospitals along the orbital track were alerted for their possible use, and some near planned landing areas were briefed by NASA–DOD teams. Early in the missions, blood was drawn from donors and made available for transfusion at Cape Canaveral and in the recovery area. As the operation grew wider in scope involving the Pacific, and as more confidence was gained, dependence was placed upon walking blood-bank donors who were typed, and drawn blood was available only in the launch-site area.

In conclusion, Project Mercury gave the opportunity to define more closely the medical problem areas, and we anticipate the future with great expectations and confidence in man's ability to adapt to and conquer this new frontier.

FUTURE PLANS

As we look at future missions in two-man Gemini and three-man Apollo vehicles, there are some changes aside from crew size which pose potential problems. The maximum mission durations planned for both these projects is 14 days. This is a considerable increase over the 34-hour duration thus far flown. We hope to reach this duration by incremental steps to learn more about man's response to the weightless environment. We are particularly anxious, of course, to gain further information concerning the responses of his cardiovascular system as well as those of the musculoskeletal system, particularly as regard calcium balance.

In the lunar program for the first time, there will be an operational demand to have the suit, which has traditionally served as a backup pressurization system, serve as a primary system while the astronaut explores the lunar surface. This has caused some special attention to be paid to the development of various aspects of this suit in consideration for additional thermal protection and micrometric protection.

Mobility in a pressurized suit in the 1/6-g lunar gravity is also a problem undergoing careful evaluation at the present time. We will first try exposures to the actual space environment in a suit in the Gemini program, by having an astronaut open a hatch and stand up and finally, actually depart the Gemini spacecraft on a tether and spend varying periods of time in free space.

Waste disposal and personal hygiene become problems of concern on these prolonged missions; they have not been of concern on our short-duration missions. We have decided that provisions must be made for defecation, and the Gemini suit has been so designed. The system to be utilized, however, has some psychologically less acceptable features than in the Apollo program where we can use the more conventional bathroom approach due to the space and weight limitations available. Body cleansing will be provided by the use of bactericidal agent present in small pads. A special vacuum-cleaner-type shaver is being designed in order that the loose whiskers will not be free in the weightless environment. A special ingestable dentifrice-type tablet has also been designed to provide proper oral hygiene.

The proper establishment of work-rest cycles is of importance on these long missions and particularly so in a lunar mission where the lunar excursion phase alone could last for a period of 48 hours. The multicrew operations will require modifications of our preparation in recovery procedures, and our countdowns will either have to be lengthened, or we will have to provide multiple examination and preparation teams.

We look forward to these programs in the future manned orbiting laboratories and Mars missions with a great deal of anticipation and with still a firm feeling that man will be able to adapt to and conquer this new environment.

N64-30345

SPACE-CABIN ATMOSPHERES

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In spite of early philosophical objections to manned space flight, it is evident that man's presence is a valuable asset in assuring success of the scientific exploration of the solar system. The problem now placed in the lap of the scientific community is the assurance that man will be able to utilize his priceless superiority over the machine in this effort.

In the selection of ideal space-cabin atmospheres there has arisen a fascinating interaction between human physiology, the gaseous environment, the machine, and the mission. The systems approach, which has been so useful an aid in the selection of ideal hardware, must be brought to bear once again. I shall attempt to outline the major reasons for uncertainty in the selection of space-cabin atmospheres and the problem of optimizing the man-machine system in this respect.

The manned flights of the United States and Russia have been successfully accomplished with diametrically opposed philosophies regarding cabin environments. The Russians have chosen for their flights an oxygen-nitrogen environment of essentially the same composition and pressure as air at sea level. With less of a weight problem than the United States has had, their philosophy has been "Better the devil you know than the one you don't." In Project Mercury, simplicity of control engineering and minimization of weight were considerations which led to selection of 100 percent oxygen at 5 psi as the cabin atmosphere. Current plans for Gemini are to repeat the successful 100 percent oxygen of Project Mercury. These plans extend to the 14-day Apollo program, but with much less certainty than in the past. The use of 50 percent oxygen in nitrogen at 390 mm Hg (7 psi) or ½ atmosphere has been seriously considered and is still being studied as a possible choice.

These represent only three of the many possible gaseous environments. Unfortunately, the pressure of engineering commitments involved in the development of spacecraft requires that decisions be made early, often before the physiological tolerance to unnatural gaseous environments can be determined. In the past, selection has been primarily on engineering grounds, with the burden of proof on the physiologist that such environments cannot be tolerated. While this approach has been adequate for previous flights, it has serious drawbacks for the longer and more hazardous missions of the future. The cost and complexity of physiological studies of exotic gaseous environments appear justified not only by these mission considerations but by the light which they can shed on the problems of respiratory physiology and pathology which still plague us on Earth.

The variables of the cabin environment which must be considered are:

1. Total pressure
2. Oxygen pressure
3. Carbon dioxide pressure
4. Inert-gas pressure
5. Water-vapor pressure
6. Gaseous trace contaminants
7. Thermal properties of gas
8. Circulation of gas
9. Temperature of gas
10. Leakage rate of gas
11. Duration of exposure
12. Gravitation level

There are also numerous physiological and pathological variables on which these environmental variables may act:

1. Alertness and performance
2. Communication

3. Time of useful function
4. Decompression syndromes
    (a) Aeroembolism and bends
    (b) Barootitis and barosinusitis
    (c) Cardiovascular collapse
5. Respiratory physiology
    (a) Atelectasis
    (b) Hypoxia
    (c) Hypo- and hyper-capnia
    (d) Hemoglobin control
6. Oxygen toxicity syndrome
7. Radiation sensitivity
8. Fire and blast hazards
    (a) Meteoroid-penetration effects
    (b) Cabin-fire control
9. Bacterial flora changes and infections
10. Water physiology
11. Thermal-control problems

Lack of information beclouds the interaction between the environmental and physiological variables over long periods of time. Let us see what happened to some of the simpler environmental variables in previous space flights. Ideally, the temperature in a cabin should be 60° to 80° F and humidity 40 to 70 percent. In the early Mercury flights, trouble with the temperature-control system caused excessively high temperatures during early phases of the mission. The humidity-control system also had its difficulties. These arose primarily through action of another variable—gravity. In zero gravity, the control of waterflow becomes quite tricky and devices for adequate humidity control require ingenious engineering. The rather moist state of most of the Mercury astronauts testifies to the difficulties of water control that may arise in experimental programs. Future zero-gravity technology may be expected to improve these systems. A complicating factor is the tendency to integrate systems. The integration steps bring up new potential problems which, as always, appear at most embarrassing times in an otherwise successful system.

Now, what about carbon dioxide? Studies of carbon dioxide hazards in nuclear submarines have led to the concept that for prolonged periods of time this gas should be kept below 0.5 percent in the atmosphere. In the Mercury program, this control was successful. However, as flight durations are prolonged and simple chemical absorption systems are replaced with complicated devices which can regenerate oxygen from carbon dioxide, the danger of malfunction rears its ugly head.

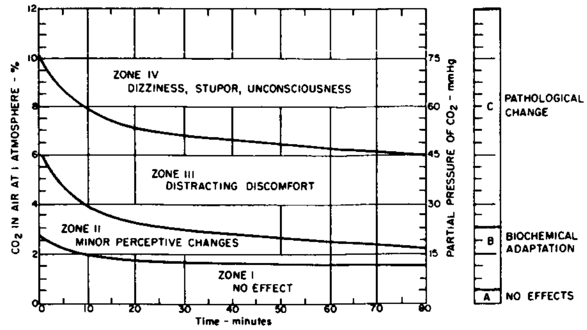

FIGURE 1.—Effects of carbon dioxide on man.

Figure 1 illustrates some of the problems which carbon dioxide alone will give us. At high concentrations, exposure for short periods of time causes dizziness, stupor, and unconsciousness. These exposures may arise in a fire situation as a result of either fire or fire extinguishers. At lower levels, after longer periods of time, carbon dioxide can cause distracting discomfort which may interfere with a mission. At very low levels, biochemical changes occur which, though not a danger *per se,* may well combine with other stresses to get the astronaut into difficulty. This is especially true in the case of oxygen poisoning.

The selection of total pressure within a space cabin has been determined by engineering considerations. In past designs it was felt that cabin pressure had to be kept below 5 lb/sq in. or about 1/3 atmosphere to avoid the excessive weight of cabin wall required to maintain higher pressures. Recent studies have shown that an increase in the pressure to 7 lb/sq in. can be handled with a weight increase of only 8 pounds. As technology improves, one may find that cabins of 1 atmosphere are compatible with the weight requirements of the overall mission. Filament-wound fiber glass plastics are being considered as a weight-saving device. These create other problems which remain to be solved, such as the effects of hard vacuums on the plastic fillers between fibers and the effect of meteorite penetration.

For every total pressure in a sealed cabin there is an optimum percentage of oxygen and a range above and below which there is danger. Figure 2 summarizes most of what is known about this relationship. In order to keep the oxygen pressure in the lungs equivalent to sea level, one must increase the oxygen percentage as the pressure is reduced. The sea-level-equivalent line is presented on the graph. Thus, at 24,000 feet, over 60 percent oxygen is re-

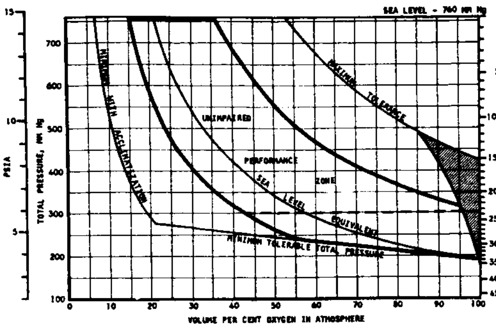

FIGURE 2.—Oxygen-pressure effects. (After Luft.)

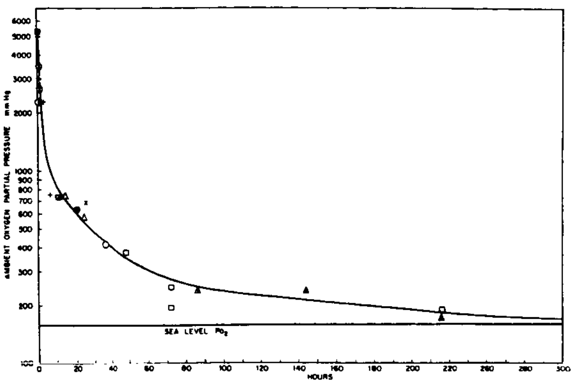

FIGURE 3.—The time factor in oxygen toxicity. (After B. E. Welch.)

quired. At 33,000 feet, 100 percent oxygen is required. The body can tolerate oxygen levels in the lungs lower than sea level without impairment. The lower heavy curve in figure 2 represents the lower limit of unimpaired function. Any cabin or suit system must be kept above this line.

What about excessive oxygen or the problem of oxygen poisoning? Unfortunately, man has not been designed to tolerate excess oxygen. Deep-sea fish are the only creatures that face, in nature, the problem of excess oxygen. Through the ages, even sea-level animals have recurrently faced the problem of oxygen deficiency for short periods of time and have developed elaborate devices to compensate for this unhappy state. With no exposure to excess oxygen pressure to direct the evolution of physiological devices, land animals have developed none. The upper heavy curve in figure 2 represents the onset of oxygen toxicity. At sea level, over 40 percent oxygen for long periods of time leads to pathological changes in the lungs. Oxygen tents in hospitals leak in enough air to keep patients out of danger from oxygen toxicity. As the pressure within a sealed cabin is reduced, the percentage of oxygen can be increased without danger to the crew. This is fine for space cabins where the lowest possible pressure is best from an engineering point of view. Fine, except for one point. As we approach 100 percent oxygen, the general rules of the game appear to change. Results of recent studies of 14 days' duration have suggested that there is a possible danger after exposure to pressures of oxygen slightly above the sea-level oxygen pressure. This is most unfortunate, since engineers would appreciate the simplicity of controlling only one gas.

It is true that Astronaut Cooper was exposed to such pressures for 34 hours without obvious ill effects. However, both animal and human experiments suggest that he just slipped under the wire.

Figure 3 is a review made by Dr. Welch at the U.S. Air Force School of Aerospace Medicine, Brooks Air Force Base, of the time factor in oxygen toxicity. All points above the curve represent symptoms of oxygen poisoning. The experimental points represent time of onset of first symptoms. Deep-sea divers get into trouble with oxygen pressures in the 2,000 to 6,000 mm Hg range. They suffer nausea, dizziness, convulsions, and loss of consciousness within several minutes to hours. Humans exposed to 80 or 90 percent oxygen at sea level have no nervous symptoms but suffer coughing and pneumonia after about 1 day's exposure. The exposure of Astronaut Cooper fell at the 250 mm Hg, 34-hour point, just below the line.

Recent experiments at several laboratories have shown a variety of late symptoms occurring below ½ atmosphere of pure oxygen. The most common symptom is earache caused by the absorption of oxygen from the middle ear during sleep. This is similar to ear discomfort from change in altitude. Chest pain has been reported, as has decreased breathing capacity on maximum effort. These symptoms have been attributed to collapse of lung segments or atelectasis. The inert gas, nitrogen, ordinarily acts as a brake to prevent collapse of the lungs. When one breathes 100 percent oxygen, the rapid uptake of this gas by the blood often empties the alveoli or air sacs and collapses the lung segments. Of greater concern have been isolated cases of paralysis and liver damage in animals under these conditions. These may have been due to the triggering of virus infections by the slight elevation in oxygen tension. Human subjects have come down with severe anemias and kidney damage after 60 to 80 hours.

What is not clear is the role of nitrogen in the physiological processes and the role of trace contaminants in the sealed cabins which can react or combine with the unusual oxygen environment to produce undefined toxic agents. In any event, the use of 100 percent oxygen environments is not without danger. Recent studies in the space-cabin simulator at the U.S. Air Force School of Aerospace Medicine, using 100 percent oxygen at 5 psi for 30 days, have resulted in no symptoms. This would suggest that the 14-day Apollo mission may be safe under such conditions, providing the cabin does not produce unusual chemical agents which may, even in trace amounts, combine with oxygen to give unexpected trouble. It will take full simulation in the Apollo vehicle for up to 30 days to eliminate cryptic toxic hazards.

Because carbon dioxide can dilate blood vessels in the brain and lungs, this gas increases the danger of any given pressure of oxygen. Another interesting synergism is the additive effect of oxygen and radiation. Both oxygen and radiation appear to destroy cells by a common mechanism. They both generate free radicals or very active compounds which destroy critical structures. Thus, the solar and cosmic radiation hazards in space missions intensify oxygen problems and vice versa. Much work is still required to define the synergism.

The problem of oxygen toxicity in space has very definite parallels in clinical medicine. In recent years clinicians have used sealed chambers with several atmospheres of oxygen to increase the oxygen content of the blood in such disorders as tetanus, carbon monoxide poisoning, strokes, myocardial infarcts, and many other disorders where critical pathology is a matter of local oxygen defect. This approach to hypoxic states recently came to the public interest when it was used, though unsuccessfully, on the child of our late President. Understanding of the subtle cellular changes in space-cabin environments will go a long way in defining the changes brought about by this new therapeutic device.

The synergism between oxygen and radiation also has clinical implications. The sensitivity of internal tissues to radiation can be modified by placing patients in high-oxygen environments. It thus may be possible to increase the effective internal X-ray dose without increasing the skin dose. Since damage to the skin often limits a radiologist's approach to cancer therapy, it is quite important that the subtleties of the "oxygen effect" be adequately studied. Here again, the basic problems of space medicine and clinical medicine run parallel paths. Both should benefit from research directed against common problems.

Other changes may well occur with elevation of oxygen pressures. Bacterial flora on the skin and in the mouths of subjects exposed to unusual oxygen environments do change. Many of the anaerobic bacteria are killed and thus the ecology of these surface organs is changed. So far, no symptoms have arisen in experimental subjects, but one must consider the long-range effect on such phenomena as dental caries and gum disorders. Once again, these studies should shed light on the natural ecological balances of the body surfaces in earthy environments.

What about the fire hazard? We all know that combustibles burn at much greater rates in oxygen. Is this a tolerable hazard in space vehicles? A recent review by the Lovelace Foundation has shed some light on the fire and blast hazard in space cabins. The effects of inert gases in the combustion process have been studied in the past for the prime purpose of developing equations which define the combustion process for engine applications. In space cabins this role of inert gases has very direct and practical implications to the designer.

In recent years there have been two relatively serious fires in cabin simulators using 100 percent oxygen. Analysis of these fires suggests that there remains much work to be done in the selection of fabrics, plastics, and combustible liquids of all types for high-oxygen environments. This selection process will have

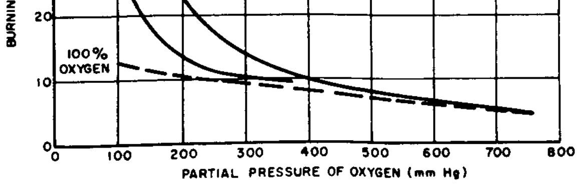

FIGURE 4.—Effect of oxygen pressure on burning time. (Modified from Parker and Ekberg.)

much carryover in the design of high-pressure chambers for therapeutic purposes. Fortunately, there have been no therapy-chamber accidents, but the hazard still looms large.

Can the fire danger of 100 percent oxygen environments be tolerated in space cabins? What are some of the numbers involved? Figure 4 indicates that the rate of burning in the 100 percent oxygen atmosphere of the Mercury cabin is almost 3 times the rate in air at sea level. The ignition energies required for gases can be several orders of magnitude greater in 100 percent oxygen than in air. Conversion of flame to detonation is aided by increasing oxygen. Fireproofing agents effective at sea level are no longer effective with elevation of oxygen to even as little as 40 percent. Most of the fireproofing data stem from studies by the British welding industry. New methods of welding involving exotic materials and techniques will benefit from studies of fireproofing in space-cabin atmospheres.

A fascinating study is the relative effect of different inert gases on the overall fire hazard. Is any one gas overwhelmingly better than the others in the space cabin? Unfortunately, theories of the physical chemistry of the combustion process predict that each burning parameter will be affected differently. The confusion is pointed out by table I, which shows that each factor has its own optimum gas. Consensus by the combustion community favors nitrogen, but this is based more on intuition than cold fact. A missing link in the whole picture is the role of zero gravity. Absence of convection does reduce the burning process, but the degree of safety to be afforded by this state is yet to be determined. Lack of convection, however, increases the tendency to form hot spots and aggravates ignition problems. Absence of gravity also modifies fire-extinguishing techniques in that the dense vapors used on Earth lose their blanketing effect. Extinguishing vapors in a cabin present severe toxic hazards which are currently under evaluation. The basic concepts of fire prevention and extinguishment on Earth will be greatly expanded by the need to understand the space-cabin problem.

The possibility of meteoroid penetration must also be considered. The injection of liquid metal into a cabin by a penetrating meteoroid presents a serious blast and flash problem within the cabin. The danger of lung blast is probably minimal for particles with energy great enough to just penetrate the wall of the cabin. Larger particles could cause lung damage, but

TABLE I.—*Summary of Effects of Inert Gases on Flame Propagation (after C. E. Mellish and J. W. Linnett, "The Influence of Inert Gases on Some Flame Phenomena," in Fourth Symposium (International) on Combustion, The William & Wilkins Co., Baltimore, 1953)*

In reducing burning velocities	$CO_2 > N_2 > A > He$
In decreasing composition range for flammability:	
Wide tubes	$CO_2 > N_2 > He > A$
2.2 cm diam	$CO_2 > He > N_2 > A$
1.6 cm diam	$He > CO_2 > N_2 > A$
In increasing minimum spark-ignition pressure:	
$(H_2 + O_2)$, low pressure	$He > A > N_2 > CO_2$
$(H_2 + O_2)$, high pressure	$CO_2 > N_2 > A$
$(H_2 + N_2O)$, low pressure	$He > CO_2 > N_2 > A$
In increasing minimum spark-ignition energy:	
$(H_2 + O_2)$, atm. pressure	$He > CO_2 > N_2 > A$
$(CH_4 + O_2)$, atm. pressure	$He > N_2 > A$
In increasing quenching distance:	
$(H_2 + O_2)$	$CO_2 > He > N_2 > A$
$(CH_4 + O_2)$	$He > N_2 > A$

these are quite rare. The flash of molten vapor in 100 percent oxygen is similar to the flashbulb effect and can produce blindness lasting as long as several minutes. From recent calculations it appears that permanent retinal blindness, as seen after nuclear flashes, will not be a problem. Ignition of combustibles such as fabrics and plastics by hot vapor is a potential hazard. Fortunately, the chances of penetration of current space vehicles by meteoroids has recently been shown to be several thousand times lower than estimated 5 years ago. Figure 5 summarizes current predictions. Except for travel in the asteroid belt, it would appear that the meteoroid problem would rank quite low as a criterion in selection of space-cabin atmospheres. The basic problem, however, is of great interest to many disciplines and is under continuing investigation.

After considering all the above arguments, is the concern about fire and blast risk resulting from 100 percent oxygen environments only academic? At first sight, the arguments presented do seemingly reduce the concern. It is easy to say that sophisticated safety design will eliminate ignition and fuel sources and that training will eliminate human error. It is also easy to rely on the dumping of cabin pressure, zero-

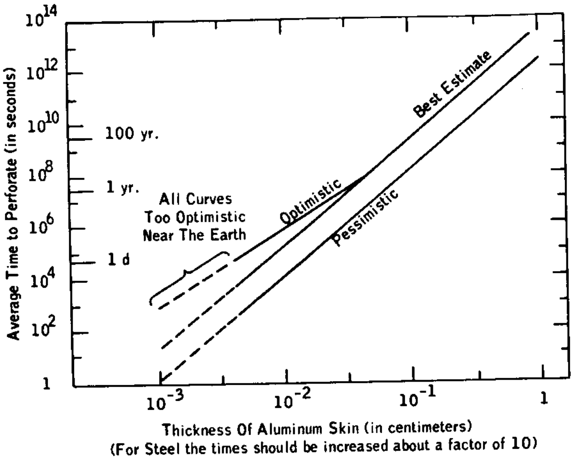

FIGURE 5.—Meteoroid perforation of thin metal skin. in space. (After F. L. Whipple, "On Meteoroids and Penetration," presented at the Interplanetary Missions Conference, American Astronautical Soc., Jan. 1963.)

gravity fire attenuation, and detector-extinguisher systems as backup for potential design failures. It is difficult, however, to assign to many of these factors a probability of success or failure. The ultimate question, of course, is this: Is the increase in overall probability of mission failure brought about by the fire risk of 100 percent oxygen environments greater than the overall probability of failure brought about by the added weight and complexity of a multigas cabin system? The fire risk of 100 percent oxygen is one aspect of the problem. The risk of oxygen toxicity, already discussed, is another. The two must be added together to assess the overall risk of 100 percent oxygen environments.

The general engineering approach must take into account all probabilities of the fire risk. Figure 6 indicates a simplified scheme of how a computer program can approach the problem. Such studies are currently being attempted, but the number of unknowns in the space-cabin environments makes such an approach seem quite naive. More data on the physical processes involved will help validate the method. In conclusion, it cannot be stated with certainty on the basis of present data that, as regards fire hazard alone, 100 percent oxygen should be eliminated as an atmospheric environment in space cabins. The closer to the 8,000-foot air atmosphere of the present-day commercial airliner, the safer the choice. Any compromise of this "ideal" should be in favor of more inert diluent and lower total pressure. Also, the more closely the ideal fire-prevention design and the ideal detection and extinguishing systems are approximated, the less significant becomes the choice of atmosphere. Simulation of the burning hazards in unmanned orbiting vehicles is expensive, but may in the last analysis be the most fruitful source of information for design decisions.

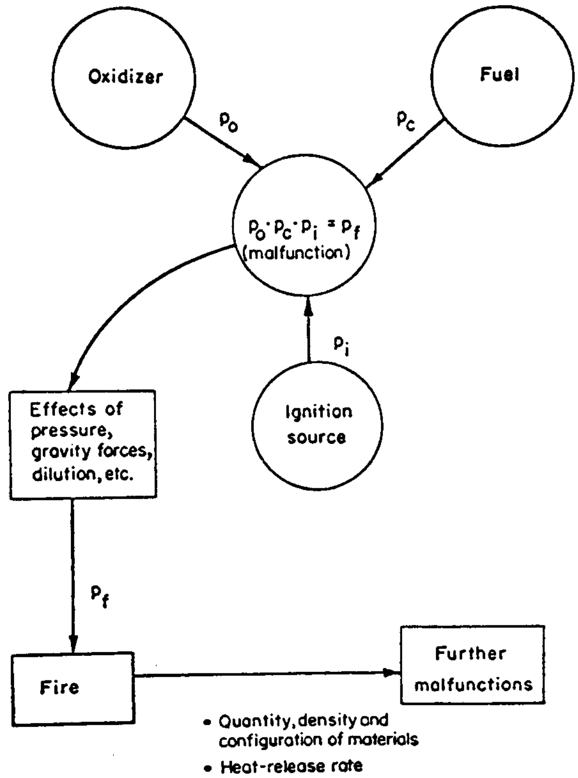

FIGURE 6.—The fire situation. (After H. Cary et al., "A Study of Reliability of Flight-Vehicle Fire-Protective Equipment," ASD TR 61–65, Battelle Memorial Inst., 1961; ASTIA No. AD–268574.)

Lastly, why should we worry about the presence of inert gases in the space cabin? The major factor appears to be the decompression problem. For many decades divers and aviators have been exposed to this hazard. Sudden reduction of pressure releases the dissolved gases in the bloodstream and tissues to form bubbles. These bubbles cause severe joint pains called "the bends," and often give more serious

trouble in the form of cardiovascular and nervous-system collapse. Penetration of space vehicles by meteoroids or by accidents of varied types requires that the crew protect themselves against decompression. Unfortunately, space suits provide pressure equivalents of 30,000 to 40,000 feet, pressures low enough to cause bends. If the crewman must get about and exercise vigorously to repair the damage, his susceptibility to bends increases.

Nitrogen, unfortunately, is very soluble in the fats of the body and can form these bubbles quite readily. It can be shown that after decompression this gas would be more hazardous than helium or neon, though less hazardous than argon, krypton, or xenon. Unfortunately, we know man can exist indefinitely in nitrogen; we are not sure about helium; and we are completely in the dark about neon. Actually, until recent months there has been absolutely no biological data on neon. Helium does have some queer metabolic effects on lower animals, but it seems to be tolerated by monkeys for periods as long as 14 days at 7 atmospheres pressure. The U.S. Navy has started similar studies on man. Helium has been shown to be more favorable than nitrogen in regard to bends after prolonged underwater exposure. There is reason to believe that helium will be more favorable than nitrogen after space decompressions. Neon should, theoretically, be more favorable than nitrogen but less favorable than helium. However, since neon is more efficiently stored in cryogenic form and offers less leak wastage than does helium, it remains a serious candidate for space cabins.

For cabins with 50 percent oxygen in nitrogen at ½ atmosphere, a seriously considered alternate in the Apollo project, decompression should not be a danger. Recent studies have shown that this environment, even after prolonged exposure, reduces the dissolved nitrogen enough to minimize bends complications in space suits. In the less likely cabins with 1 atmosphere pressure, helium or neon appears to be a better candidate. Interestingly enough, "the devil we don't know"—100 percent oxygen—is the most favorable gas in decompression events. We are today quite ignorant of the role of inert gases in physiological processes. We have evolved in a nitrogen environment and have adapted to it biochemically. There have been recent reports that suggest that nitrogen is needed in the atmosphere for embryological development, but subsequent attempts to repeat these experiments have led to equivocal results. Clinically, the role of inert gases has much theoretical significance. Many of the anesthetic agents are as "biochemically inert" as the noble gases, but have profound physiological effects. The specific mechanism of action of these agents is still unknown. Since nitrogen at high pressure and krypton and xenon at sea level can be anesthetic agents, it would appear that these gases present excellent model systems for studying anesthesia. The space program has already stimulated several projects along this line, and more appear to be springing up every day. Our long neglect of this fascinating area has finally come to an end.

Thus, we see that choosing a space-cabin atmosphere represents a rather complex decision. It must be tailored to the vehicle, to the mission, and to the state of knowledge regarding many physical and biochemical variables. The more complex space-station and interplanetary missions will no doubt add to the confusion. However, as in most scientific areas, the period of confusion leads to one of more complete understanding, simplification, and utilization. The hurried confusion of space science is no exception.

WORKING FOR SPACE

Chairman
RAYMOND A. BAUER
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N64-30346

GOVERNMENT AND INDUSTRY

ROBERT C. SEAMANS, JR.
Associate Administrator
National Aeronautics and
Space Administration

During the previous sessions, attention has been centered primarily on scientific and technical aspects of the space program. Today we are taking up subjects that are less glamorous, but certainly just as deserving of our best thought and effort. Maintaining and improving the close cooperation of government, industry, and the scientific community is a primary concern essential to mission success.

Almost every project NASA has undertaken during the past 5½ years has been characterized by newness and innovation. In many ways the space program has been without precedent. It is, therefore, not surprising that along with our efforts to solve the problems of space exploration, we have found it necessary to devote a great deal of study to determining the best ways of managing a program of this scope.

In our early efforts to overtake the lead of the Soviet Union and gain preeminence in space, we had to form an organization and draw together a number of separate organizations and programs.

To accomplish this, NASA from the start has continually appraised its organizational structure and management methods. We have made every effort to meet the needs for change as they have arisen. Problems have never been permitted to pile up to the point where a major overhaul or massive reorganization was required in order to get on with the mission.

NASA PROGRAM

This is not the time nor the place to go into a lengthy discussion of the changes made over the years in NASA's internal structure. In brief, our philosophy is to limit our inhouse activity—except for a relatively small amount of research for which existing Government laboratories have a special competence—to supervising, integrating, and administering our contracts with industry, universities, and private research organizations.

The discussions of this conference so far divide easily into four general areas:

1. Manned Space Flight
2. Space Science and Applications
3. Advanced Research and Technology
4. Tracking and Data Acquisition.

Manned Space Flight Program

The Manned Space Flight program has as its objective the exploration and utilization of space by man. Steps toward this goal involve the development of a capability for extending stay times in space, the development of techniques for rendezvous and docking in space, and the capability for landing men on the Moon and returning them safely to Earth by the end of this decade. Integral with this program is the development of new and powerful large launch vehicles with the associated capability for constructing, testing, and launching these vehicles and their complex manned payloads. This has been and will continue to be a difficult program, but one which we have every confidence of being able to accomplish.

Space Science and Applications Program

In the Space Science and Applications program, we are interested in developing our understanding of the Earth and the space about it, our solar system, our galaxy, neighboring galaxies, and the interplanetary space; in this program we are producing the technology that provides the basis for the commercial development of operational space systems such as weather and communications satellites. We are study-

ing the Moon, the Sun, and the nearby planets. Investigations of the nearby planets include efforts to determine the existence and possible forms of life on their surfaces. The program also examines the effects of space environment on terrestrial forms of life.

Advanced Research and Technology Program

The prime objective of the Advanced Research and Technology program is the provision of a broad, sound, technical base for this Nation's future aeronautics and space activities. Much of this effort is conducted within Government, university, and NASA laboratories. However, some flight projects are required to support the laboratory program. The fields of interest range from propulsion to spacecraft, aircraft, and human factors.

Tracking and Data Acquisition Program

The Tracking and Data Acquisition program supports all the manned and unmanned missions of NASA. Its worldwide operation is an essential element of the total NASA program. It is obvious that from the space and aeronautics missions little will be gained unless useful data are returned to our engineers and scientists.

PROGRAMING CONCEPTS

We use the term *programing* in NASA to cover the total process of establishing goals, breaking these goals down into specific feasible missions, phasing these missions in such a way as to take maximum advantage of each mission's results in terms of subsequent missions, and applying appropriate emphasis to these missions in terms of the country's and NASA's total available resources.

An examination of our scientific objectives in space shows that a key element is the collection and evaluation of data and information. This collection and evaluation is a cyclic process (fig. 1). Gaps in man's knowledge, whether in terms of basic natural phenomena or in methods and techniques, excite possible theories based on knowledge already available. Substantiation of a new scientific concept must be based on flight experimentation. In other words, a theory on the origin of the Moon must be translated into measurable facts which support or deny that theory. The measuring instrumentation is carried aboard spacecraft designed for space-flight missions. The actual data, once collected, must be returned to Earth and thence to the experimenters who originated the theory and often developed the measuring instrument. A comparison of the anticipated and actual data permits either validation or rejection of the theory.

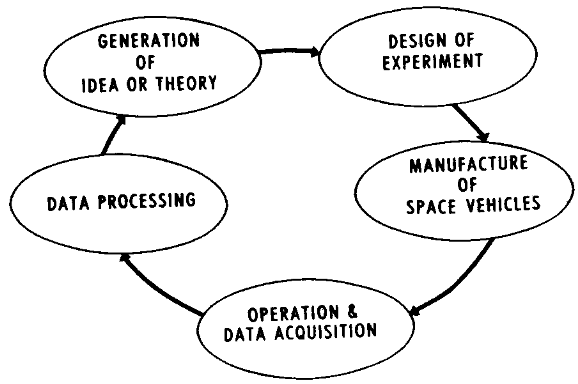

FIGURE 1.—Project cycle.

The advancement of technological developments for space operations follows the same type of cyclic process. Theoretical concepts are derived in Government, university, and industrial laboratories for modified or new types of propulsion, power, stabilization, guidance, communications, life support, structures, and reentry techniques that might lead to improved launch-vehicle and spacecraft capability. Experimental models are designed, fabricated, and tested to prove or disprove the concept. Oftentimes this requires extensive ground-based facilities such as wind tunnels, shock tubes, and space chambers. Ultimately, as in the attainment of scientific objectives, flight tests are required to confirm or deny the theoretical and laboratory results.

The entire cycle for both scientific investigation and technology advancement takes an extended period of time because it includes the design and fabrication of spacecraft, launch vehicles, tracking and data acquisition systems; and development of computing and analysis techniques. The new can build on the old only at a given pace, and to force that pace or interrupt it can be extremely damaging to the orderly and economic prosecution of our space program.

There are three variable factors that must be continuously considered in the management of our programs, namely, performance, cost, and time. It is possible to affect any one of these at the expense of the others. We make every effort to attain required performance within our budgetary authorization. We

must take the time to conceive, design, build, and test experiments of excellent quality and high value. We relax our target-flight dates grudgingly, but we must recognize that success is measured in terms of the usefulness of the data received and that abortive flights which provide little or no return waste valuable resources.

The program that we develop, then, is phased in terms of time and resources. The flexibility that we must have in our programing is required by the unknowns that we face as we convert long-range objectives into specific missions and experiments. Each major program is composed of individual projects, and most of these projects are translated into individual flight missions.

In making a decision to hold a flight for further ground test or for equipment modification, we must consider the three factors: data return, cost, and time. As the status of individual projects continues to change, we must make decisions that maximize data return and minimize costs and loss of time.

We have attempted to achieve these objectives in our program through extensive ground tests and checkout. Where warranted, we have provided backup spacecraft and launch vehicles to help insure data return. In addition, we are conservative in our launch operations. It is our policy not to launch unless there is every reasonable assurance that the mission will be successful. Flights have been scrubbed and schedules changed to allow reexamination of systems, replacement of suspected parts, and even redesign.

One measure of the effectiveness of this conservative launch policy is measured by the record of successful launched, as shown in figure 2. In 1958 through 1960 the NASA record of flight successes to total flights was about 50 percent. Since 1960 the successes have increased steadily. In 1963 the successes were 85 percent.

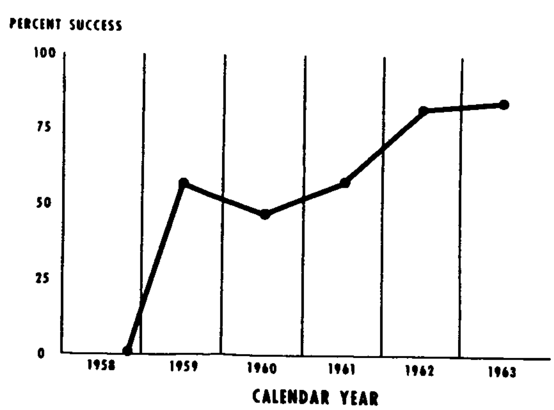

FIGURE 2.—Space flight record.

NASA is the integrating force that carries the final responsibility for mission selection and approach, launch and flight operations, and data collection. However, the growing success of our space-flight program results from the efforts made by Government, university, and industry people. We recognize that these groups of scientists, engineers, technicians, and managers represent our national collective knowledge and capability in aerospace science and technology. These teams have the capability of furthering our understanding of space and advancing our space technology, and of applying these efforts to the general welfare and security of the Nation. Because these groups are important to our future well-being, we are most interested in maintaining a well-directed, balanced program that makes most effective use of these resources.

UNIVERSITY AND INDUSTRY PARTICIPATION

The agency has experienced rapid growth as an organization and has had a commensurate increase in its responsibilities. This growth is perhaps best reflected in the resources NASA has commanded (fig. 3). Our first full year of operation, fiscal year 1959, was at a program level of $335 million and a staffing level of 9,286 people. In this fiscal year we have a program of over $5 billion and a staff of nearly 33,000. The maturing of our organization and its program is reflected in the proposed fiscal year 1965 levels of $5.3 billion and 33,800 positions.

The strength of NASA lies in its field centers (fig. 4). It is here that the work is carried out, either inhouse or by contract. Our centers are widely spread around the country and fall into two basic categories. There are the former NACA laboratories, oriented toward research and advanced technical development. There are the newer space-flight centers, which have grown up since 1958 with a flight project orientation. It is these latter that are responsible for the major contracting efforts of the agency. This distinction is becoming less pronounced as the research centers take on major projects such as the Centaur and Scout launch vehicles, a biological satellite, and a high-speed reentry probe.

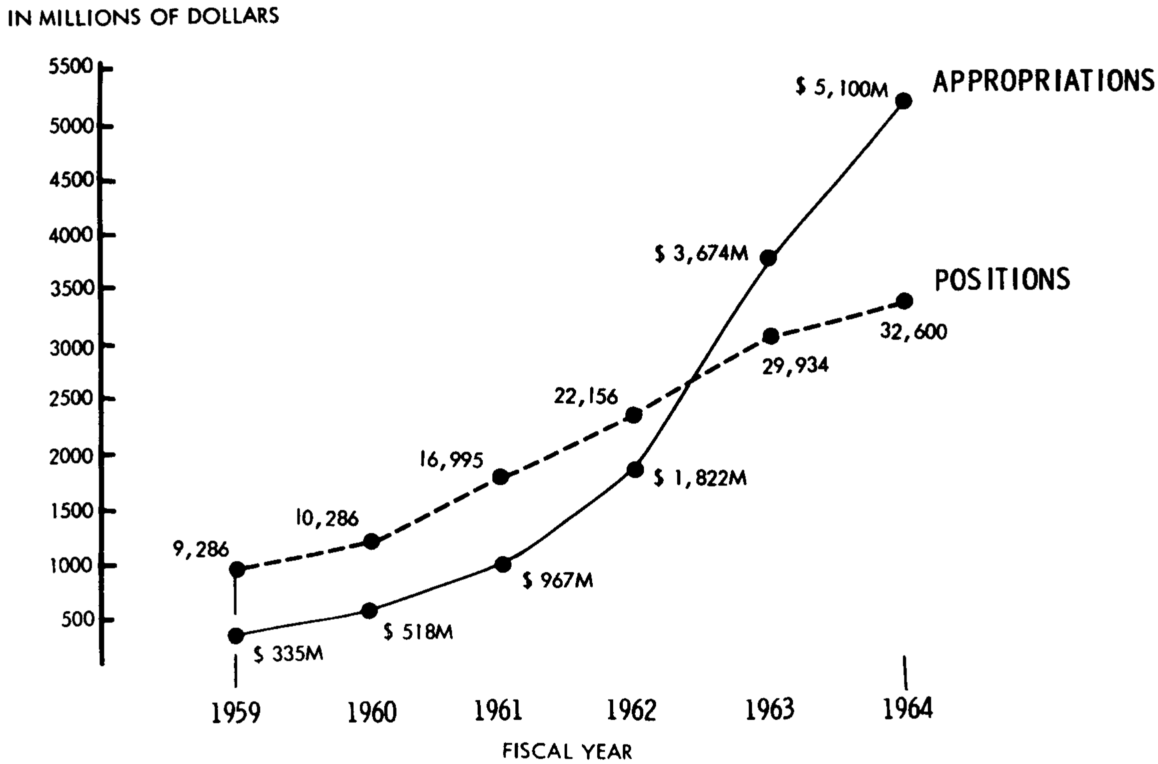

FIGURE 3.—NASA resources.

As our workload has changed and grown, so has our contractor activity (table I). Before 1958, most effort was inhouse and purchasing was limited to parts and components and to facilities construction. In the early NASA years, we began to turn to established contractors who had been carrying out the Department of Defense projects. Today, we deal with the full spectrum: Universities that do research, that provide flight experiments and that train engineers and scientists; nonprofit organizations that provide technical direction to industrial teams; and major primes with responsibility for entire long-term projects. And each of these is but the first tier in the long chain of subcontractors, vendors, and suppliers.

TABLE I.—*NASA Procurement by Type of Contractor*

Type of contractor	Millions per fiscal year			
	1960	1961	1962	1963
Private industry	$174.0	$423.3	$1,030.1	$2,261.7
Educational institutions and nonprofit organizations	17.0	24.5	50.2	102.2
Jet Propulsion Laboratory	38.3	86.0	148.5	230.2
Other Government agencies	107.4	221.7	321.8	636.4
Total contracts	$336.7	$755.5	$1,550.6	$3,230.5
Approximate percentage of NASA budget	65+	80+	90	90

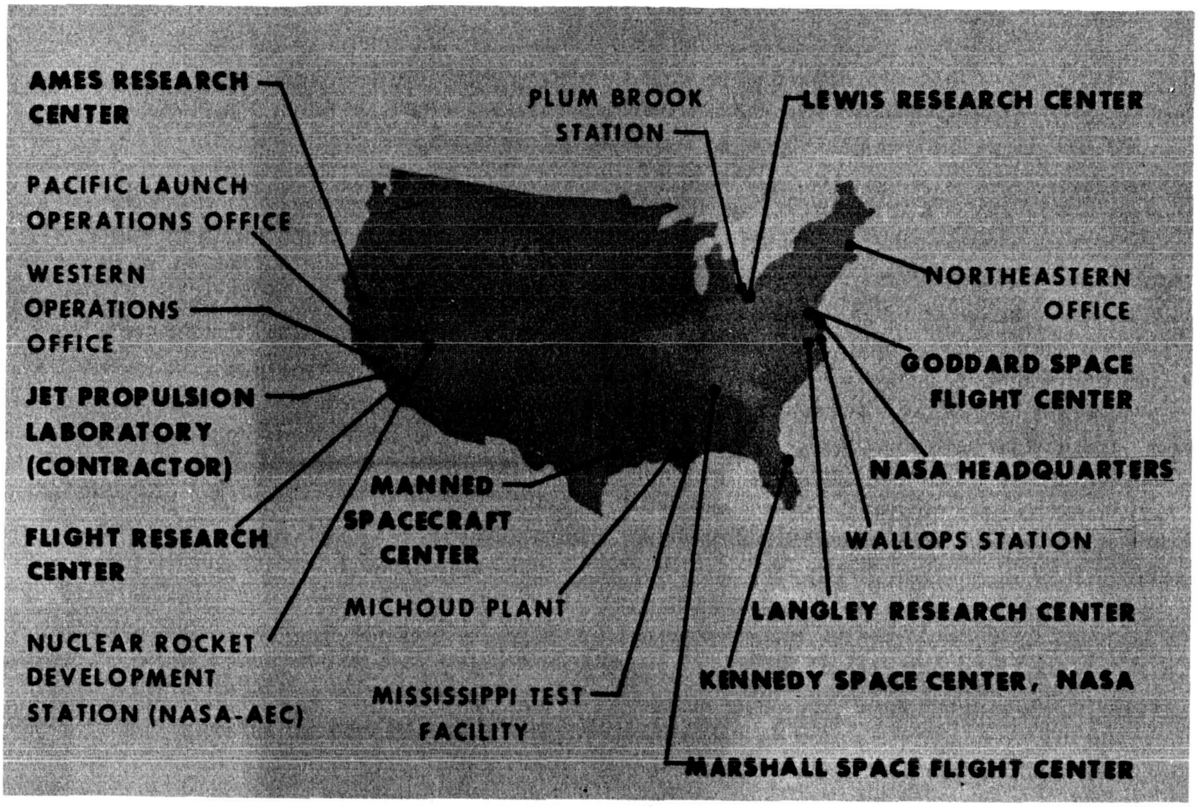

FIGURE 4.—NASA installations.

Almost 93 percent of NASA's work is performed under contract with industry. As indicated in Table II, 70 percent of the total procurements are placed directly by NASA, 5.4 percent through the Jet Propulsion Laboratory, and 17.5 through other Government agencies.

Some 2,500 prime contractors, located in 49 States and the District of Columbia, are engaged in NASA work. Something over $4 billion will be paid to industry for its work under NASA contracts this year.

Less impressive from a dollar-and-cents viewpoint, but of basic importance to our program, is the research into the space environment—its measurement, observation, and use—that is being conducted in more than 100 university laboratories throughout the Nation. More than 4,000 experimenters are participating in this work, in cooperation with at least 20 Government agencies.

CONTRACTING PROCEDURES

In view of all this, it is clear that NASA's contracting policies, practices, and administration are a key part of our overall management process.

TABLE II.—*Industry's Role in NASA Program for Fiscal Year 1963*

How contracts are placed	Millions	Portion of total procurements, %
Directly by NASA	$2,261.7	70.0
Through JPL	174.8	5.4
Through other Government agencies.*	565.2	17.5
Total	3,001.7	92.9

*Army 55%, USAF 36%, Navy 4%, others 5%.

We have had to learn—sometimes the hard way—about the many ways that the form of an original contract will affect the quality of a contractor's management and the end product that he contributed to the program.

Much of our initial work, in particular, was exploratory or "first-of-a-kind," and as a result NASA

has often been faced with a serious problem in its endeavors to develop firm specifications and to estimate costs in situations of substantial technological uncertainty. For these reasons, many of our early research and development contracts were on a cost-plus-fixed-fee (CPFF) basis. This appeared to be the best way to give NASA project management the flexibility needed to respond to changes in technological requirements.

It was recognized, even at the time, that the management of such contracts could be influenced to only a relatively limited extent by governmental administrative controls. This is not meant to imply, of course, either a blanket condemnation of CPFF contracts or a dismissal of the importance of administrative controls. On the contrary, they offered us in many cases what was probably the only way to proceed with our early projects.

What we need to do, in the future, is to devise original types of research and development contracts whose form and provisions can strongly motivate industrial management toward improving methods, and ultimately, products. It is for this reason that we in NASA have devoted so much of our attention to ways of improving our contracting processes and contract forms.

Because of varying practices in effect at a number of the NASA centers, nonuniformities in administration of contracts has sometimes been a problem. So many different elements were drawn together to make up the new agency that this development was more or less to be expected. However, we are taking steps to achieve uniform methods as rapidly as possible. There are still a number of important areas that are in need of attention, and we are collaborating with the Department of Defense in this regard.

Finally, improper use of letter contracts has sometimes been a serious source of potential trouble. These lessen the Government's bargaining power at the negotiating table. They often slow down the definitizing process, and in extreme cases can lead to situations which approach the illegal cost-plus-percentage-of-cost relationship. We have found the letter contract to be a generally unsatisfactory way of doing business, even if a cost-plus-incentive contract is finally reached. As a matter of policy, we are striving to eliminate letter contracts except in some very special cases where a specific exception is made in NASA headquarters.

It is almost always easier to pinpoint the shortcomings of contracting procedures than it is to come up with new and better ways of achieving the objective. We believe, however, that we have made considerable progress in doing both. Without ruling out CPFF contracts entirely, we recognize the chief difficulty is that the profit is to all intents and purposes built in at the beginning of a project, on the basis of estimated costs at the time; it, therefore, does not relate nearly so much as it should to the manner in which the contractor actually performs.

Along with this deficiency come other problems—different but closely related. There is no real financial penalty to the contractor who performs poorly, or overruns his costs, or misuses his manpower by pulling people off the job to help write proposals being submitted in efforts to get other contracts. Yet another important deficiency of CPFF contracts is that there is no workable financial deterrent or penalty that can be taken against a contractor that underbids the job to make sure that he gets it and then escalates the cost once the contract is firmly in hand.

There is no reward for efficiency, and no penalty for its absence, even in those overhead and administrative areas which do not relate directly to the technical effort. There can be little accomplished by governmental monitoring of such items because efficiency stems from correctly making literally thousands of small, day-to-day decisions by contractor personnel. A Government followup would simply add that much more to the costs.

To put things into the vernacular of the "carrot and the stick," we are primarily interested in a bigger and better carrot, but we recognize that we cannot afford to throw away the stick. During the past year, we have experimented with a variety of incentive forms of contracts. At the same time, we took steps to begin converting some of our existing CPFF contracts into some form of incentive contracts.

INCENTIVE CONTRACTS

We are searching for a type of contract that will motivate the contractor to become more deeply involved in performing work of high quality with maximum speed and minimum cost.

In this way we hope to reduce the number of persons presently required to carry out what are essentially policing actions. These would be largely unnecessary if we could place more of the responsibility for basic decisions of performance, time, and cost in

the hands of industry management. Only through such an approach can we hope to reverse the constant escalation of costs that stems from adding persons on both sides of the equation. This is, as the Government adds people, the contractor has to add people to respond to our people, and the result is not satisfactory to either side.

Going into incentive contracting is not, of course, an easy matter. It is hard to properly establish the incentives in the manner in which they relate to cost and schedule, and particularly to performance—how do you measure performance? But these are the things we are working on and think we are making good progress. We do have some of these contracts working for us now. Table III shows our increased emphasis on incentive contracts, from none at all in 1961 to some 30 as of April 1964.

TABLE III.—*Emphasis on Incentive Contracts*

Fiscal year	Number of contracts	Value in millions
1961	None	....
1962	1	$ 7
1963	7	162
To February 1964*	23	313

*At this date 18 additional contracts of over $5 million each were also under negotiation with selected contractors.

Again it should be emphasized that there are three factors we want the contractor to be involved in—cost, time, and performance (fig. 5). We want contracts to be written in such a way that industry management will carefully weigh and consider what any change in his operation will do to all three items. Obviously, there cannot be an alteration in any one of them without a concomitant effect on the other two. We believe that only in this way can the present performance be improved at the contractor level.

The incentive principle holds that a contractor's profit should be related to his ability to: turn out a product that meets significantly advanced performance goals, improve on the contract schedule, substantially reduce the cost of the work, or complete the project under a weighted combination of some or all of these objectives. The principle is not a new one, but the emphasis that it is receiving is new, and it is the

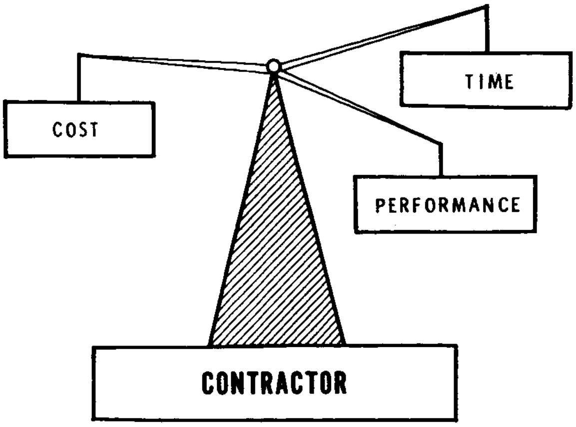

FIGURE 5.—Incentive contracting.

core of a major evolution in NASA's procurement policy and practice.

Probably the most important advantage of the incentive contract is that, since profit depends on how well the contractor performs, there is an extremely strong motivation for the contractor to do his utmost. There is a further benefit in that the incentive arrangement forces both parties to consider performance versus schedule versus cost throughout the program.

The gains that we achieve through incentive contracting are not achieved without additional effort, and certainly not without incurring certain risks. If the incentive contract places too much emphasis on reducing costs, the contractor may be tempted to cut costs at the expense of timely delivery or product quality.

We believe, however, that this can be prevented by weighting the various features of bonus and penalty to channel the contractor's efforts to meet all objectives.

In this regard, it might be mentioned that we are exploring the possibility of incorporating much sharper cost reduction incentives in those administrative and overhead areas that do not affect the technical effort. The objective, briefly and simply, is to tailor incentives to each particular case, programmatically and functionally.

This is also a good discipline from the standpoint of NASA's internal operation. These remarks are certainly not intended to imply that the need for improvement applies to industry only; we are fully as concerned with improving the manner in which we carry out our business in-house. It is our aim when-

ever possible, through careful planning, to define our contracts more clearly and accurately before they are let.

It is clear that the Government's goal must be to procure the maximum effective effort at the most reasonable combination of costs and time. At the same time, NASA needs to maintain flexibility in that as many management and procurement alternatives should remain open to us as possible during the life of the project. And we cannot neglect our responsibility of assuring appropriate quality of performance.

In terms of procurement practice, the ideal approach to a wholly new NASA flight project might run along these lines. First, we would contract with a number of companies for an advanced study which would be designed to establish the broad concepts and various approaches to a given mission or groups of missions. Such contractors would be competitively selected on the basis of the quality of the technical teams they would propose to make available for this task. This group of contracts dealing with the proposed new project would normally be fixed price and all funded at the same level.

After the results have been evaluated by NASA, the next step would be a detailed feasibility and preliminary design effort based on the work already done. NASA would have the opportunity here of selecting two or more of the study contractors based on the previous competition or might compete again with the thought of selecting the top teams that are proposed. This phase of the cycle would normally be CPFF but subject to careful direction by the field center project management group. At the time the feasibility studies are undertaken, it would be made clear that the follow-on development effort leading to flight hardware would, if approved, be let to the more effective contractor.

At the appropriate moment in the conduct of the parallel feasibility studies, NASA would select one for continuation while terminating the others. The contractor selected for continuation would then be awarded a CPFF phase I contract. This would not include flight hardware but would cover the detailed design specification, bread-board models, and test schedules required for the final project. During this phase, the detailed project cost estimates and schedule alternatives would be developed.

When the decision is made to continue into the flight hardware stage, an incentive contract would be negotiated on the basis of the total previous effort and the agreed upon designs and testing programs. The incentive phase would normally include the proof test models and the first several flight units required for missions accomplishment.

In the event that follow-on hardware items are required, two alternates are open: (1) a fixed-price continuation with the original contractor or (2) a fixed-price competitive contract based on the detailed drawings and designs prepared under the previous incentive contract.

This outline of the ideal procurement approach is necessarily a difficult one to follow in that it requires the maximum NASA engineering effort prior to actually having a contractor on board and apparently requires more time between initiation and flight than other approaches. On the first point, greater effort spent in the area of specifications and systems conceptual design will pay dividends in the form of lower total project cost and higher reliability and higher probability of mission success. As to the second point, sometimes the longest route really is the shortest way home.

We believe that by establishing discipline in such a way that incentive profits accrue from keeping costs down, meeting or beating schedules, and maintaining high standards of quality and workmanship, we will afford maximum benefit to both industry and Government.

What we are really striving for, in the final analysis, is not some esoteric, far-out goal. We are striving for mission success, while meeting our schedules and staying within cost.

We have been making—and will continue to make—every effort to ensure that working for NASA will be attractive to industry, providing, of course, that the work is well done. We want success to be extremely attractive. Conversely, we intend to make failure, sloppy work, or wastefulness of the taxpayers' dollars extremely *un*attractive.

We believe that a contract should be designed to encourage industry to be as proficient as possible, rather than assume that industry requires constant policing. If top industrial management is motivated to become deeply and personally involved in the work they are performing for NASA, the risks to themselves and to the Government will be minimized. By proper use of this team concept, we believe it will be

possible to achieve pre-eminence in space in this decade.

GOALS FOR THIS DECADE

We plan to develop the Saturn I–B and Saturn V launch vehicles capable of placing 34,000 pounds and 220,000 pounds, respectively, in Earth orbit. We will have facilities for manufacturing, testing, and launching these vehicles with the Apollo spacecraft. We will have tracking stations, tracking ships, worldwide communications, and mission control facilities for manned flight in Earth orbit and out to the vicinity of the Moon. We will have a thorough understanding of the space environment about the Earth, between the Earth and the Moon, and we will have investigated the lunar surface and selected possible landing sites. These major program elements are scheduled so that a manned lunar landing and return can be conducted in this decade. Technological progress, environmental conditions in space, and dedication of purpose will determine whether we attain these goals on this target schedule.

These goals cannot be achieved without a proper partner relationship of Government, industry, and universities. It is the acceptance of this challenge by all three participants that will, in the long run, permit success or lead to failure. Our most difficult job is to provide the appropriate framework of incentives and controls that allows and nourishes this all-important joint participation.

N64-30347

GOVERNMENT AND UNIVERSITIES

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In the words used in the advance program to characterize today's session, "American success in the space age is predicated on the creative cooperation of Government, industry, university." Dr. Seamans discussed the Government-industry phase of this cooperation. It is my privilege to describe to you the relationship which has evolved between NASA and the universities.

At the beginning of the 20th Century, the Federal Government, the academic community, and industry behaved in most ways as independent entities whose fields of influence hardly touched. By the close of World War I, the interdependence of Government and industry had been established beyond any real doubt and was generally accepted; but the university remained a thing apart. It educated, in a more or less classical sense, a relatively small fraction of the population which was able to afford the luxury; but its contribution to what we now call "highly trained manpower," with direct resultant utility to society, was mainly in such fields as medicine, law, and the clergy.

Of course, the university was also the locale of scientific research. Largely uninfluenced by any demanding technology, this research proceeded in a leisurely and protected environment of scholarly inquiry. The principal motives were curiosity and the desire to exercise intellect. Publications were proudly esoteric in style, and there was little or no organized attempt to make the results of truly scientific endeavors known to the lay public, Government, or industry in general.

Technology was primarily the responsibility of industry. Concentrated largely in the chemical and automotive fields, it was limited in its scope and extent as much by the desires and production capabilities of the sponsoring industry as by the amount of fundamental information available. No external stress demanded the kinds of drastic changes which only completely new concepts can generate, and no particular premium was placed on ultrashort response time in converting new principles into useful end items.

World War II changed all this. Under the pressure of military requirements, the customary roles of various segments of the economy were reexamined, and the Federal Government undertook mobilization of our total national resources on a crash basis. New fundamental knowledge, when quickly reduced to practice and employed against a less knowledgable enemy, became a determinant in global conflict. In short, teachers, scientists, and engineers in universities were discovered to have ideas and capabilities which could contribute to the winning of wars!

In their own laboratories and in hastily erected Government installations, university people applied their imagination and creative talent to the struggle for national survival. The traditional disciplines of physics, chemistry, biology, psychology, electrical, and mechanical engineering merged into new areas of development of radar, sonar, biological and chemical warfare, nuclear energy, human factors, propulsion, and ordnance. The drives of pure curiosity and self-satisfaction gave way before the external urging of operational requirements.

The total effort was successful, and eventually the war ended. Some of the scientists and engineers who had been uprooted from their academic environments stayed with Government or with industry; others returned to the universities to begin rebuilding. But both Government and universities had learned a lesson which was not soon to be forgotten—and which was to prove as important in peaceful pursuits as in war—

namely, that true cooperation was the key to the successful accomplishment of things neither could possibly do alone.

During the following decade, a number of Federal agencies began to draw upon the scientific and technical resources available to our postwar society. Universities and Government began the long and sometimes painful process of learning to understand each other and to work together for the long-term common welfare. Some Government agencies, such as Defense, began to develop relationships along lines which followed their wartime associations. New ones strongly dependent upon modern technology, such as the Atomic Energy Commission, recognized the contribution which universities could make to the accomplishment of their mission.

When NASA came upon the scene in 1958, a number of basic principles and mechanisms for the conduct of research in universities under Government auspices had been developed. Through their participation in the research programs of Federal agencies, universities had become much more conscious of their direct role in the accomplishment of long-range national goals.

With the passage of the National Aeronautics and Space Act in 1958, NASA undertook the pursuit of three broad, essential objectives:

1. Expansion of human knowledge of space phenomena
2. Advancement of the technology of space flight and aeronautics
3. Development of the capability to apply aeronautical and space techniques to peaceful uses of mankind.

The challenge was a formidable one. It was plainly evident that, in such an undertaking, the common enemy was ignorance, and new knowledge would be the only effective weapon against it. In each area, NASA drew heavily upon the capabilities of universities. Each program office sought the help of specialized talent in solving its own particular problems—a natural stimulus for the initiation of research projects in qualified universities all across the nation. This became NASA's sponsored research program—a direct response to our programatic needs.

During the first 3 years of its existence, NASA devoted about $25 million to sponsored research and flight instrumentation in universities. With these relatively modest funds, universities began engaging in research across a broad spectrum of fields—many of which had been sorely neglected—ranging from astrophysics and astronomy to aerospace medicine and exobiology, from fluid mechanics and plasmas to communication, data processing, and systems analysis.

In March 1961, the President announced the acceleration of the national space program. Every component of NASA took stock of its strengths and weaknesses, examined its policies and procedures, and reevaluated its available resources. The critical reappraisal of NASA-university relationships revealed several clear facts:

1. Universities were already contributing significantly to the research needed by the national space program. This sponsored project research was vitally necessary and should be continued and augmented where required.
2. NASA and the Nation had needs which were not adequately satisfied by this sponsored research alone.
3. Many universities were able and anxious to do more but were constrained by the structuring of existing programs and apprehensive of greatly expanded project-type efforts which might destroy the institutions' internal balance. New administrative, organizational, and management concepts were at least as necessary as funds to implement new activities.
4. No other Federal agency was utilizing this reserve capability.
5. NASA could take advantage of this opportunity to strengthen its own program by using techniques which simultaneously improve the ability of universities to perform their unique and traditional functions and allow them the latitude necessary to optimize their performance while still remaining responsive to NASA's total mission requirements.

Working from these premises, NASA convened a group of 16 eminent members of the academic community who, together with nearly an equal number of NASA representatives, examined the general problem of strengthening NASA-university relationships. Upon the conclusions reached during these meetings in July and August of 1961, we developed the basic principles which have guided our relationships with universities during the past two years. Central to the development of such principles and the design of programs which give them form and substance is the

recognition of the need for new knowledge. NASA needs it to solve the problems which may prevent accomplishment of its mission—some of which cannot even be foreseen now. Universities, at least at the graduate level, have traditionally been involved in the total process of dealing with this knowledge—encouraging and implementing its generation, exchanging it among faculty and students, and communicating it to the rest of society.

Research, upon which we depend for the organized increase in our store of knowledge, cannot proceed without three basic ingredients: skilled people, adequate laboratory facilities, and support of day-to-day operations. Routine support of project-oriented research customarily concerns itself primarily with the last of these, since both requirements and results in this area are easier to identify and evaluate. This kind of research, with its direct responsiveness to specific technological program objectives, remains the major element of our university endeavors. We are proud of the accomplishments it has made possible during the past several years, and we have increased our sponsorship as NASA has grown. In addition, however, we have established other activities which augment and complement this project research, namely:

1. Encouragement and support of multidisciplinary research of special character which may be unsuitable for conventional project treatment
2. Graduate training in space-related science and engineering
3. Assistance in the provision of adequate university laboratory facilities for space-oriented research.

The first of these implements the view expressed by Mr. James E. Webb, Administrator of NASA, in a recent public statement:

> Our policy is to place research contracts and grants at those universities where the scholars themselves, the consensus of the faculty, and the administration of the university are interested in having the work progress on a broad interdisciplinary basis, drawing together creative minds, knowledge, and resources from many fields, . . . for widely shared participation. Under this policy, NASA research proceeds within the university in the closest association with graduate and post-graduate education, thereby replenishing and augmenting the supply of highly qualified scientists, social scientists, engineers, and technical experts.

These special purpose research grants offer universities a considerable degree of flexibility in making maximum use of their research capabilities. Some help fill gaps between related research projects, allow exploration of new avenues of investigation, or encourage the development of creative multidisciplinary enterprises. Others allow consolidation of associated activities or bring out the latent talent of groups which, by virtue of their size or experience, have not yet been able to participate in the space program.

We believe strongly that research which traditionally and rightfully belongs in the university should remain there and should be part of the normal university functions and responsibilities. Accordingly, we are not inclined favorably toward proposals to divert NASA funds for university research away from the central university complex or to create special research centers which diminish the side benefits of intimate association with the total educational process. Our efforts will, we hope, enable universities to strengthen themselves at the same time that they increase their role in support of this long-range national undertaking.

A growing space program will place increasing demands on the already limited supply of highly skilled scientists and engineers. The demand will be in two general directions—those technical personnel required to participate directly in the immediate programs of current space activity to solve current problems and those required to conduct basic research of a long-range nature, to teach new students and, equally important, to study and comprehend the vast amounts of scientific data acquired through increasing space experimentation.

In this country, the complex job of training or teaching, the conduct of basic research, and the attack on the fundamental problems of nature are concentrated in the university, where all three functions are part of our traditional educational system and to which our nation looks for the leadership in understanding the environment in which we live.

We all know that the doctoral degree is not the sole measure of advanced academic excellence and the trained mind, but it is the most reliable and uniform yardstick we have. Immediately upon acceleration of the national space program in 1961, NASA initiated a predoctoral training program, designed to help avoid an acute manpower crisis 3 or 4 years from now which might result in raids on other segments of the economy. This program provides 3-year predoctoral training opportunities to selected graduate students with the ultimate goal of acquiring their Ph. D. de-

grees. Training grants are made to the university, not to individual students. Under a principle of maximum local autonomy, trainees are selected by the senior members of the faculty who will supervise their graduate studies. The stipends and allowances granted are competitive but not so lucrative as to draw off from other areas of the institution, those students who would normally study in other fields.

Participation as a NASA trainee gives the student a direct identification with NASA goals and problems. It gives him the feeling of being involved in the bold new programs of the space age. In many cases, his professors at the university are directly engaged in research activity supported by NASA, so that the student also has a direct association with NASA scientists and space-oriented experiments. The ties thus formed provide additional motivation to the trainee to continue studies in this area and participate in some part of the national space program after graduation, at which time he is free to remain in academic work or to affiliate with industry or Government.

By the fall of 1964, 1,957 NASA predoctoral trainees will be participating in this program at 131 universities across the country. Eventually, we expect to be responsible for a yield of about 1,000 Ph. D.'s per year, a fair NASA share of the increased supply of highly trained talent which this Nation's technological growth is estimated to require.

In addition to our involvement in research and the stimulation of advanced training, NASA is authorized to grant funds to universities for the construction of laboratory facilities urgently needed for the proper conduct of research in space-related science and technology. By facilities, we mean exclusively buildings — "brick and mortar" — not research equipment. NASA does not customarily make equipment grants as such, but prefers to consider research efforts as whole entities, including the necessary instruments and tools to do the job.

Few would deny the importance of suitable facilities for industrial design, fabrication, or flight testing in industry; and they are equally important in university research. In spite of the nostalgic appeal of the concept of sealing wax, string, and unheated garrets, obsolete and overcrowded facilities do not really generate outstanding modern research, and many universities are already literally unable to accommodate their existing talent.

Facilities grants have been made on a highly selective basis, generally to institutions which are already deeply involved in NASA work. This is no general construction program, for such an undertaking would far exceed NASA's proper sphere of activity as well as its available resources. Important though they are, we do not finance the construction of classrooms, auditoriums, libraries, or cafeterias on campuses.

As part of the negotiations surrounding each major facilities grant, NASA and the university execute a Memorandum of Understanding which embodies statements of NASA policy and philosophy and an avowal by the university of its intent to seek ways in which benefits of NASA-supported research can be applied to the business, economic, and social structure of the United States.

The medium of approach to NASA in all these undertakings is the unsolicited proposal. Although there is always room for improvement in the quality of such unsolicited proposals, we have experienced no lack of quantity. For example, during the 4 years which ended last December, NASA's Grants and Research Contracts Division received 7,820 unsolicited proposals. Not all were from universities, of course, but they included endeavors in almost every conceivable area of science and technology. Naturally, not all can be accepted. Of every five research proposals currently being received, NASA supports one. Of the other four, perhaps two are of sufficient interest to merit support if additional funds were available, one represents research which is interesting but so similar to work already in progress that we would have to regard it as unnecessary duplication in our program, and one is substandard.

New England universities have participated in every phase of these NASA programs. Nearly $17 million of NASA funds have already been directed into 82 active grants and contracts in 22 colleges and universities in the 6 New England States. Of these schools, 15 have predoctoral training grants with a total value of nearly $2.5 million, for the 3-year support of 130 graduate students in space-related science and technology. There are 75 research grants and contracts in effect at 19 of these institutions, at a total annual level of effort of about $4.6 million.

The first of our facilities to be completed and occupied was the biomedical annex to the Harvard cyclotron building. Our largest facilities grant to

date was to Massachusetts Institute of Technology (MIT) for its new Center for Space Research. One-fourth the cost of this building is being borne by MIT—an example of the cost-sharing partnership which we encourage and strive for, even though matching funds are not mandatory. Incidentally, the Administrator of NASA has determined that the national interest will best be served if title to both these structures is vested in the universities, rather than being retained by NASA. This has been done.

We are proud, as you are, of the excellence and leadership demonstrated by the universities of New England—the major contributions of the large ones and the determination of the smaller ones to grow and improve. In the pursuit of its own mission objectives—which must always be its primary motivation—NASA tries to deal with these institutions and others like them across the country, in ways which give us the benefit of their initiative and creativity while strengthening them and preserving their essential academic integrity. On such a basis, we believe a true partnership between Government and universities to be desirable, possible, mutually profitable, and contributory to the welfare of the entire United States.

N64-30348

SPACE TECHNOLOGY'S POTENTIAL FOR INDUSTRY

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The transfer of space technology to industry is a very large working interface—involving much of our new technology, many of our basic industries—and we can only assume that all *first* reports will be incomplete. So, at the beginning of these remarks, it might be useful to break down the kinds of things that flow from accelerated technical programs—such as the civilian space program. For this purpose, the results of these programs can be sorted into three principal classifications.

First is *specific products and components* which include weather satellites, communications satellites, fuel cells, rocket engines, boosters, and guidance equipment. The benefits that will come from improved communications or more accurate weather predictions, for example, are too numerous to mention, but a few remarks as to the relative costs of such systems compared to costs of other means of doing the same thing are pertinent. One expert in the communication industry has said that a single satellite costing about $40 million and placed in a 22,300-mile-high orbit could accommodate as much traffic as a system of ground and submarine cables costing over 10 times as much.

Similarly, the cost of providing weather observations from a satellite is not expensive when we consider the area covered. A weather ship in the North Pacific, the birthplace of much of our weather, costs about $1 million to maintain and operate annually, but it can observe an area of only about 200 square miles. A weather satellite costs about four times as much—$4½ million—but it can observe an area of approximately 640,000 square miles in each picture it takes!

Thus, the cost advantage of observatory or communications satellites makes them immediate candidates for transfer to commercial application.

Second, are the *technologies* developed by such projects; from these flow back advances in materials, new reliability and quality-control measures, and process development such as thin-film circuitry and micro-miniaturization.

For a typical booster such as Atlas/Agena, the cost of launching satellites into a 6,000-mile orbit is approximately $10,000 per pound, and the payload is limited. Weight savings through miniaturization of electronic components, then, receive high order priority. Miniaturization, one of the most significant developments in industry in recent years, has received continuing stimulus from the needs of the space program to reach the ultimate in weight savings and reliability. But this technology will have impressive impact in greater value and service to the customer in consumer and industrial products as these advances are reflected there in the future.

The two-way flow of technological developments in materials is also worth noting. For example, in the electrical lighting industry years ago, research in high-temperature resistance led to some special but unneeded materials, such as pyrolytic graphite, which were never useful in lamps—but which now find important applications in the space program.

The third element, flowing from our space efforts, is *the advancement of the general technical-managerial climate*—creating continually higher standards for technical and program management.

The sheer size and complexity of space projects (as of many recent military undertakings) is sharpening the role of management. The techniques developed to cope with the monstrous complexities of such

projects will be useful in many other fields. These will be useful as applied in greatly expanding services and controls such as urban transit systems or air traffic control. The requirements for high-order reliability and performance to schedule and budget, where many absolute and unpredictable unknowns exist, cannot help but tune program management techniques to greater effectiveness wherever they are used.

Space and defense work embraces the toughest kind of technical problems (every job is one which has never been done before) with impossible schedules under tight budget limitations, and against some of the roughest competition in the world. These kinds of challenges amount to feeding raw meat to our management, our engineers, and our scientists.

In keeping with our national goals, and the extent of the challenge involved, there has been a tremendous flow of technical capability and business information into the civilian space program. This is a field characterized by rapid technological progress, keyed more to unique requirements than to competitive economic factors. Time scales for development tend to be short and obsolescence rapid. Requirements are continually becoming more severe. That is, environmental conditions are increasingly unfamiliar and hostile, the amount of power needed is growing, accuracy of regulation and control must be better and better, and the sources of energy are becoming more diverse. Once limited to the airplane engine itself or a wind-driven propeller generator, the aerospace designer must now take into consideration the use of combustible gases in fuel cells, adaptability of atomic reactors, radioactive isotopes, sunlight, radio or light waves beamed from the ground, and, perhaps, even the photochemical energy of the atmosphere through which the aerospacecraft will fly. Once limited to radio transmitters and receivers, lights, and a few instruments, the electrical load to be supplied now may include comfort heating and cooling, ventilating, oxygen and water regeneration, food processing, entertainment, vehicle stabilization, and, perhaps, even propulsion. Once restricted to 20,000 or 30,000 feet altitude and a few hundred miles an hour, the environmental conditions now include devastating vibration, high-acceleration takeoff conditions, the searing heat of hypersonic reentry through the upper atmosphere, the nearly perfect vacuum, and the deadly radiation disturbances of outer space, with no dependable gravitational field to keep convection processes going and men and equipment safely in place.

What are we bringing back from this great venture to the extremes of our techniques? In asking, we should be aware that the results may not be what we expect. In fact, the use of a scientific or technological development is often quite different from what was originally intended.

In the past, the creation of a new technology in one field has had an impact on many others. The automobile industry was largely responsible for such developments as efficient internal combustion engines, alloy steels, synthetic rubber, and new fuels. The aircraft industry created a wide market for aluminum alloys, which now have countless industrial uses. Similarly, the great technological advances of our space industry will have, in time, tremendous implications for all of us though many will never leave the Earth.

Although the space age is only 6 years old, a number of people have been concerned about the relatively slow rate of transfer of space technology developments and their commercial application. Thus, the Denver Research Institution Study concludes that "relatively little importance can be attached to the direct transfer of products from missile/space programs to the civilian sector of the economy at this time."

The National Aeronautics and Space Administration and its administrator, James Webb, placed a great deal of importance on this problem in 1962 and established within the NASA Office of Applications an industrial applications group, to act as a catalyst for provoking a technological fallout from space to the civilian economy. This group contracted with the Midwest Research Institute in Kansas City to uncover potential applications of space technology to industrial and consumer products, to document them and to circulate them to industry. Also working for this industrial applications group, the Denver Research Institute found 145 carefully screened examples where industry was making products and using processes originating in the national space effort.

This was only a start, but an important one. Requirements which we do not now foresee will generate uses for present space-oriented technologies as the increasing complexity of our civilization brings these needs to the fore.

In this context, however, we must remember that a *time-lag* really does exist by the very nature of the problem. It will also vary as we look again at the three types of transfers that we might expect to flow from our space program.

Out of No. 1, *specific products and components,* if our assumptions are correct, there will be a few isolated items for which there are already a foreseeable requirement and an economic basis. Examples are the already-mentioned communications satellites, which in spite of their very big price tag can fill a need for more communications services more economically than other ways. To some extent the same thing would also apply to weather satellites and to the whole field of communications in space activities which promises to make startling advances.

It is noteworthy in the above examples that one of the basic parameters enabling transfer is the cost parameter. Also, a need, or "market", already exists. One of the functions of business is the entrepreneurial function of exploiting a need or want for an innovation that did not previously exist to satisfy a requirement, and a part of the usually considerable timelag from scientific development to product in use may be spent simply in persuading the public—through product promotion—that the innovation really matters and will provide the service needed more effectively than any other method.

There are also highly important peripheral conditions which make possible the use or need for a product—where advances in the product generate the requirement for advances in related equipment and vice versa.

Witness the classic example of the Model T, and the development of individual transport in this country. In 1900, a few more than 4,000 passenger automobiles were sold in the factory. They were an enthusiast's or a rich man's hobby. It took 20 years before factory sales topped 1 million. It took only 5 years for sales to rise nearly 1 million more. What was going on in this time? Technical progress, of course, but progress was not paced only by technology. All those other relevant forces that attend the growth of a product, an enterprise, and an industry were in the picture over the years. The development of greatly improved roadways and highway systems were needed to provide the "need" for auto volume. Sales organizations, advertising, repair shops, service stations, highways, motor vehicle codes, driver's tests and licenses—all the developments like these came on the scene to influence one another and the total expansion of the industry.

In a recent TV program, Bob Newhart summed it up this way: "The man who invented the wheel didn't accomplish much, but the fellow who put four of them together really had something."

Although space science was underway in this country only 5 years after the first plane flight, with Robert Hutchin Goodard's experiments in the basement of the Worcester Polytechnic Institute in Massachusetts, large expenditures on missile/space programs have been made only in recent years, and there has not been sufficient time for many product transfers as such to take place. Most of this transfer is still well ahead of us.

No. 2, *the tranfer of technology,* rather than of products, will be by far the most important for some time to come.

The least promising transfers are the systems and devices in the first category—because the systems and their components are the optimum for very specialized, very complex functions which seem unlikely to be economically adaptable to widespread needs in the home or industry.

In the process of system optimization, the field of aerospace is especially characterized by the fact that low weight, small size, and high reliability have become far more important than direct cost. It would probably not be correct to say that systems optimization is more important in the aerospace field than in other fields—it is extremely important in all fields. However, it may well be more difficult because the number of parameters to be taken into consideration is generally larger. Furthermore, the overall system optimization must generally be carried out with respect to overall mission performance rather than with respect to a single system alone, which complicates the task of the aerospace designer.

Some very promising transfers do appear, on the other hand, in the areas of new materials, new design approaches, and new production techniques. Many of them are true innovations; they offer new ways of performing old or new functions—new shortcuts, better performance, lower cost. But they are seedlings brought out in a special climate of cost and time urgency. Adapting them for commercial growth in the climate of economic competition will require further time and effort but will bear fruit.

Dramatic, but limited, examples are the cardiac pacer and the patient-monitoring devices made possible by the aerospace industry's success in miniaturizing electronic components.

Here a promising further development is taking place at our Valley Forge Space Technology Center,

where bioscientists in the Space Sciences Laboratory, working under a contract from NASA, have successfully demonstrated that useable electrical power can be drawn from living animals. This means that in the future such lifesaving devices as the heart pacer, or heart pump as it is sometimes called, may be powered without cumbersome and failure-prone batteries. And some day . . . in the future . . . transmitters implanted in the human body and powered by the body's own electricity may telemeter back to a doctor's office a continuous report on the state of a patient's health.

It is probably more meaningful and accurate, for some time to come, to consider space contributions to the commercial area in terms of the transfer of technology rather than in terms of the transfer of products. Materials, processes, manufacturing techniques, operating procedures, and new standards born of space requirements will replace many such commercial practices currently in use to provide products which will better fill the needs to which they are oriented.

The third category, that of *the increased ability of industry to manage large, complicated systems* with the related engineering, manufacturing, and financing requirements, and their controls, is a factor which will transpose to industry on a more nearly current basis. This is an educational process, and this education in the forms of achievement of new standards of excellence, the nature of problems which have to be solved, the pitfalls against which we must guard in the future, the importance of timely integration in technical and operational areas, and the myriad of related problems, is part of the heritage of anyone and everyone associated with the space program. As these people and their associates work on new problems, as their efforts are used in new fields, as they change job assignments, and as they receive promotions to more influential positions, a great many of the advanced operational techniques, together with the seasoning brought about by the underlying experiences, will be sprinkled throughout industry and will accrue to the general benefit and well-being of industry in this country and all those affected by it.

It is patently evident that as the level of education increases in any community the benefits accrue to the overall welfare of that community and its neighbors—whether this be a civic community, a nation, or an industrial community. Thus, it is indeed the case that the entire economy of our country and the welfare of our people cannot help but realize benefits from the intensive, rigorous educational process taking place as our space work progresses. This involves broad technological advances, reliability performance requirements at a level never before encountered, extensive integration of relatively unrelated disciplines and of the contributing activities to each main event, detailed surveillance and control of schedules, costs, and performance of all the elements as well as the whole involved in each project. The benefits of this experience can never be taken away, and those who have had the advantage of it will provide an important impact in many other areas of work and on many future projects.

Now, what, if anything, do these characteristics tell about how our space efforts are, or might better be, geared into the processes of technological advance and economic growth?

The transition from a science-originated opportunity to an economic development is frequently extremely demanding of all industrial functions and resources. An example is atomic power—the Atomic Energy Act opened the door to the commercial development of atomic power in 1954. It took 10 years and a billion dollar investment by electrical manufacturers and electric utilities to make it commercial. In other words, market development and process refinement go hand in hand in importance as related to the development, invention, or technology itself.

The key technological innovation in a development may take several forms: a material with novel properties, such as semiconductor materials; a new component, such as the cryogenic gyroscope; or a novel combination of known technologies.

In research and development, technological innovation is, as has been said ". . . like golf, a game of misses." We are fortunate if a small fraction of the product of commercial research results in useful products. The game becomes one of bringing the fractions that succeed to market on a timely basis to achieve the business which makes the effort worth while.

A key person in this process is the engineer- or manager-entrepreneur, who can see commercial possibilities in the application of scientific principles and who labors to perfect usable products and techniques. This kind of entrepreneurship has become increasingly valuable as the advance of science has made available new knowledge, new products, new production methods, and new resources.

The emphasis is on the change which occurs as a result of market forces after the product or technique

has reached the commercial stage. The technical developments immediately preceding commercialization, and the contributions of the engineer-entrepreneur are of particular significance. Such contributions are the difference between invention and innovation, and the technical change is clearly affected by market forces sensed and met. It is not enough to be able to create the product; the market development to create the *need* for the product is at least as important.

This market development has to take place on a scale which *pulls* a product into widespread use, instead of attempting to *push* a product simply because you know how to manufacture it. It is almost impossible to overemphasize the importance of marketing in the process. Marketing was described in a recent issue of Forbes as "telling the customer what you can do for him, as opposed to old-fashioned selling which consisted of asking him to do something for you."

In summary, the new things that are learned and the increased abilities that are generated as a result of the space program may not constitute anything that would not have happened in the fullness of time in any case, but the concentration of effort, in order to meet extremely demanding requirements, has accelerated the development of higher technical sophistication and greater systems ability, and is of great value in itself—even though it may have arrived at this point far earlier than our consumer and industrial economy can assimilate it. We must not be too impatient for the industrial requirements to catch up, for this new technology is spawned by an unnatural (as compared to traditional) emphasis of great magnitude outside of the industrial business economy.

The eventual capabilities and applications that will come of this—slow though they may seem to us—are going to be of great importance to all of us in the years ahead.

As Alfred North Whitehead said more than half a century ago, in words that might have been written to describe our national space program:

> Modern science has imposed on humanity the necessity for wandering. Its progressive thought and its progressive technology make the transition through time, from generation to generation, a true migration into uncharted seas of adventure. The very benefit of wandering is that it is dangerous and needs skill to avert evils. We must expect, therefore, that the future will disclose dangers. It is the business of the future to be dangerous; and it is among the merits of science that it equips the future for its duties.

Let us substitute the word "opportunity" where he has used "danger."

N64-30349

NEW ENGLAND AND THE SPACE PROGRAM

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After papers by experts like Hugh Dryden, Robert Seamans, George Mueller, and Homer Newell, and by heads of the NASA Centers, what can there be left to tell about NASA? What can be added as comment on the New England scene after James Gavin, James Killian, and Jack Parker have made their remarks? Perhaps there is something that can be said about the experience of NASA's North Eastern Office over the past 19 months.

The North Eastern Office was created in September of 1962 as a kind of management experiment on the part of NASA. We were not meant to be a forerunner of an Electronics Research Center, although we have been that too, but were meant to be a new management tool of the agency.

First, NASA recognized that it could benefit from having an agent regionally involved in guiding its existing contract and grant program with the industry and the universities in the area.

Second, NASA appreciated that there was an untapped competence here that should in some way be encouraged, on its own initiative, to become a part of the Nation's space effort. After all, the Space Act of 1958 which created NASA calls upon us to use effectively the scientific and engineering resources of the Nation in the program.

Meeting the first of these goals has been a matter of establishing sufficient competence in the North Eastern Office to provide contract administration and technical monitoring and liaison services, quality assurance monitoring and training services, and educational program services.

The second goal has been a more difficult one to meet—perhaps because there are few criteria by which one can judge the degree of success achieved, and because there is a long difficult road to be followed for any contractor trying to compete successfully for space program business.

In one of Boston's papers last week, there was a report on the results of last year's Conference on the Peaceful Uses of Space that was held in Chicago.

> That Conference—was an all out effort by Chicago's business community to stimulate interest in space and science industry and garner NASA contracts.
>
> It cost us plenty to put it on—but economically we didn't benefit to a great extent.
>
> We went all out and we didn't get one single significant contract.

These statements attributed to a Chicago spokesman, illustrate one of the common misconceptions of doing business in this program. There is, in fact, no way one can ingratiate himself so that business automatically comes his way. Competition is keen and widespread throughout the Nation, and in the long run the payoff is for excellence.

We have counseled with representatives of more than 500 companies or major divisions of companies over the past 19 months; all of them thought they had something to offer NASA or one of its prime contractors. What do we see as the key to a company's success with NASA?

First, they must in fact have an idea or a product that is relevant and good enough to interest NASA's program specialists and managers.

Second, they must have the skill and persistence to market their proposal.

The most frequent problems that we have identified are associated with the second point—marketing. A company wishing to be an effective partner in this program must examine its marketing procedures on a continuing basis. This may seem to be too elementary an issue, especially to those who say they know the

importance of marketing—take another look, I urge you. There will be no panacea to problems, but the thoroughness, the persistence, and the skill employed in marketing are vital to NASA's acceptance of ideas and products. This incidentally, is as true for universities as it is for industrial concerns, both large and small.

Few of the companies represented by the audience at this conference have the resources to cover even a significant part of NASA, let alone all of it. In the interest of making fullest use of NASA's competence, the Agency is decentralized to give our Centers and program managers the greatest degree of operating autonomy. A company, on the other hand, must look for the needle in the haystack—the one office or one program to which it can contribute. It must use all of its resources as it tries to home in on its prospect—NASA's abstracts of reports, congressional reports on NASA programs, the counsel of the North Eastern Office and others who can guide contracting efforts. Of course, through your presence here you are making use of another medium—the conference, seminar, or briefing. In our experience, companies may know of these sources of assistance but do not always make optimum use of them.

New England's universities—especially those in Greater Boston—are legendary, and their influence on industry (as, for instance, represented by our Route 128 Development) is being copied the Nation over. In such places as North Carolina—where the research triangle was formed in 1954 for the purpose of strengthening the graduate study programs at three universities, and through this, enticing new research oriented industries to the state—Pittsburgh, Baltimore, Dallas, Buffalo, Minneapolis, Portland (Oregon), are all trying to emulate New England. Our universities are no longer going to be a unique asset upon which to trade. But we do still have a head start over many competitors.

Electronics has been one of the cornerstones on which much of our postwar changeover has taken place, and this has implications that extend into many fields—that of life sciences, to mention only one. The marriage between electronics and medicine is only in the honeymoon stage; its maturity in the future should be a base on which many new and exciting business ventures will be built.

What about the so-called big, prime contracts? Can New England industry compete successfully for these? Examining those awarded over the past, we find that in many instances there was no New England company bidding.

We are not suggesting there should have been bids from this region on these programs. What this does suggest is that New England companies may find limited opportunities to compete effectively for certain kinds of business because of the size and composition of our industry.

But what about subcontracts? They are going to become more and more important in the period ahead to concerns representative of New England—but only if the full ingenuity and competence of the region is brought to bear on them.

Good subcontracts under which a company can develop and realize a satisfactory return are also competed for actively; and, of course, we know of the concern of subcontracting firms over the tendency of prime contractors to do more and more of their work *in house*. Although NASA does not encourage this tendency of the "big to grow bigger", we know it as a fact of the American business scene.

Industry in New England is indeed diversified. With apologies to the larger companies, we really have no giants of the business community, or an industry such as textiles that if in trouble can deal an almost irreparable blow to our economy. This diversification fits in well with the rapidly changing technology base that supports us and should be a stabilizing influence on industrial development. Because of this diversity and because we have so many small concerns with highly developed special skills, we are still debating whether or not we need some kind of an organizational structure that would permit many companies to work as a single unit. Perhaps some banding together in formal relationships would be helpful. Attempts at this Research Foundation are being explored through the Bay State, but whatever we do must produce a substantive relationship, the advantage of which is apparent to the customer, the Government in this case, and which can not be obtained more effectively through traditional business relationships.

This paper would not be complete without some recital of the growth of NASA's stake in New England. There are substantial differences in the amount of participation of the six New England States, but NASA's prime contract awards have increased from $11.2 million in fiscal year 1961 to $24.2 in 1962, to $53.7 in 1963 and to an estimated $67.7 in 1964. This last figure is based on a projection of the first

9 months of our current fiscal year which ends this June 30, and it may turn out to be much larger than $67 million because the year was half gone before we received our appropriation. Studies made of subcontracting practices indicate about equal amounts spent in New England via this route.

Will these dollars continue to increase although it looks as if NASA's budget is leveling off? The answer to this depends more on the New England community than it does on decisions in Washington. The competition is fierce for NASA work. With the specter of defense cutbacks looming over the Nation, this competition will increase. There is no automatic percentage of even the Electronics Research Center's program that can be assured for Boston or New England. If we can adapt ourselves, be alert to an accelerated changing scene, and not hang on to the traditional beyond its usefulness, we will certainly be able to make bigger and better contributions to the Nation's space effort.

N64-30350

NEW ENGLAND'S STAKE IN THE SPACE PROGRAM

JAMES MCCORMACK
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At a Conference on the Peaceful Uses of Space, I will have to beg your forgiveness by beginning my brief commentary with a military recollection. It was just a little less than 10 years ago that I went to a specially called conference in the higher levels of the Pentagon on the subject of "What can the military services do in the way of helping out the International Geophysical Year?" One suggestion, for example, was that we might put some sort of a modest satellite in orbit—and that should surprise the Russians!

The Army and Navy together developed a program with the Navy doing what we people in the missile business were still inclined to call the warhead, although it was really the scientific package, and with the Army undertaking to hook together a Redstone and a Sergeant missile, as a first and second stage, respectively. It was thought that a ball weighing somewhere from 6 to 20 pounds could be put in a near-Earth orbit. As for the Air Force, we had a program out in Los Angeles to do something about the Atlas missile. We volunteered to pull three Atlas missiles off the production line at some time to use as first stages—it being calculated that the same little ball could be put in a lunar orbit or at least loop once around the Moon in an Earth orbit. That seems like quite a long while ago when Dr. William Pickering is talking about stabilizing one of his spaceships by using flippers sensitive to the pressure of light—it was a shorter time than 10 years ago really because we did not actually start until 6 years ago.

The future of a great deal of our technology as well as our national prestige now rests on our position in space. President Kennedy's magnificent phrase, "Space is the new ocean, and we must sail upon it," is given flesh-and-blood reality by people like Wernher von Braun.

Dr. von Braun, incidentally, was in New Mexico the first time I went there, after World War II in 1947, at White Sands where some German V–2's were being shot off—more or less to see how they worked. The thing I have recalled most about my visit is not the actual shooting of the V–2. It was a test stand for rockets which the local lieutenant colonel pointed out very proudly was designed to withstand a million-pound thrust rocket test—this was not very difficult to do because they were going to thrust upward and push down toward the rock. That was in 1947. In 1958, 11 years later, Lyndon B. Johnson, then a senator, issued a report from the Senate urging the development of the million-pound rocket.

A few words of regional interest seem appropriate here. We, all of us, go along continuously aware, subliminally aware, perhaps, of the fact that the effective groupings in society begin with the individual and progressively increase to include the family, tribe, town, city, State, and Nation. We are all aware that this politically economic grouping has grown to something even supernational. How many of us think, though, of the particular importance of groupings in the deeply science-based technological effort of the sort we are discussing here? Of course innovation comes from the minds and conceptions of gifted individuals, but it also comes from the efforts of groups. The things that the Bell Telephone Laboratories do, for example, could not be done in college laboratories and much less by individuals; even in such a loose democracy as Harvard University things happen because there is a faculty club where people meet and interact.

New England has historically excelled in the nurturing of creative individuals. We have not done as well as we could in capitalizing on the ideas created

here. Modern rocketry was really born here, but then it went away—as a matter of fact, it went all the way to Germany. And, since we are discussing flying bodies, we might add that aeronautical engineering—as opposed to the cut-and-try method of making airplanes and seeing if they would stay up—was born here, too. The first course in any university treating this subject as a discipline was initiated at MIT by Jerry Hunsaker, still here on Beacon Hill. Incidentally, he served for many years as chairman of NACA, the predecessor of NASA.

The techniques of radar which, with a bit of a head start from Britain, were developed in the World War II radiation laboratory here formed the background for one aspect of today's guidance and navigation problem, inertial guidance which was also developed in New England. The elements of the spaceship, at least the initial innovations on our shores, all started right here in New England, but the aeronautics industry, the guidance industry, and the navigation industry are not centered around here.

Some other things went away too. Technicolor was born here and moved to Hollywood. We cannot say that that sort of thing would not happen today—that we are alert to getting on top of opportunities. The one individual invention that made modern high-speed data processing—really modern and really high speed—was born right here a few years ago, but the center of the data-processing industry is not here, either. The important point is that we have opportunities from propinquity with the enormous individual talent in our region—we have a very highly intellectual atmosphere in this area. We have opportunities for translating and transferring these new ideas into useful end results. We certainly have opportunities beyond any that we have exercised. What we need to do is to match our genius, really, in innovations and technology with the sort of innovations in management that will make it possible for this community to make its really best effort.

This is only in part regionally selfish because the total strength of the Nation is the strength of the individual parts, and in this technology the translation from idea to basic research to applied science to implementation is so very important that it must be done quickly. Such translation is achieved so much more easily in groups, and, since we have such a grouping, we owe it to the country to do the best we can with it.

Dr. Killian suggested that the best course for New England was to do what comes naturally—that is, innovation: he may have coined the phrase *the innovation industry.*

Congressman Daddario raised the flag against complacency which I, also, would aim specifically at this region. One aspect of the New England genius of our highly competitive industry is that organizing them is a little bit like organizing fly fishermen. Or, to state it another way, in the context of our greatest strength there do lie elements of weakness that very much deserve our attention. General Gavin remarked that we should regard the NASA Center here as an incentive and not as competition.

Dr. Seamans showed a chart which had 18 dots on it for NASA installations—the *one* dot in New England happens to be Frank Phillips and his Procurement Office. In light of the oncoming overwhelmingly obvious fact that electronics and the things that center around the arts that we identify with electronics are going to be the tail that wags the system's dog in the space business, with this Electronics Center we have a basis for a new model of planning. The great strength of the universities of New England as well as industry also strengthens the foundation for our important role in space science.

Dr. Seamans spoke of inadequate planning being one of the difficulties in the program. It has been said on occasion that no well-organized body ever makes a small mistake. The U.S. Government is not a small body, and it is, in some respects, organized. So we are in danger of making big mistakes in the ground work we lay today. Why was it 11 years from the hopeful construction of a million-pound test stand at White Sands until a mandate from the Senate started development of a million-pound thrust rocket? Why was it even 3 years from the time when the United States recognized that it needed to put something in orbit for the International Geophysical Year until an orbiting package was developed? Even so, it took the shock of the Russians' Sputniks to really put us to work. We do make big mistakes when we make them. With this strength and with the introduction of NASA's Electronics Center here we have the basis for the truly "deep-diving" intellectual effort needed in planning that will get the right course of action laid out.

In conclusion, we New Englanders wish to express our gratitude to our excellent panel chairmen: Messrs. Knowles, Holmes, Harrington, Goett, and Bauer. We

offer a sort of a personal thanks to Dr. Kirschner and Dr. Stroud for noting some of the applications of results that have already come out of our space program in geodetic measurements and meteorology.

We especially thank Mr. Parker for his reminder that $40 million worth of communications satellites might get $400 million of capacity measured in terms of cables, and that $4 or $5 million worth of weather satellites give a scan of over more than half a million square miles as compared to 200 miles scan from a ship in the Pacific, where our weather comes from.

Our gratitude also to Messrs. Gilruth, Shea, Pickering, Dressler, Naugle, and Miller for enlightening us on the programs of NASA. Thanks, too, to Mr. Phillips for his friendly chiding which has always, in my experience, been accurate and, thus far, friendly. We especially thank Dr. Newell for his very perceptive remarks about the role of universities.

☆ U. S. GOVERNMENT PRINTING OFFICE: 1964—O 735-086